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Report of the Committee on Synthetic Detergents

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* Appointed to the Committee, respectively, on 6th July, 1954, 10tb February, 1955, and 18th May, 1954, to fill the vacancies caused by the retirements of Mr. R. Craig Wood, Mr. H. Symon, C.B., and Lieut.-Colonel E. F. W. Mackenzie, O.B.E., M.C., M.B., Ch.B., D.P.H., from the Committee as originally constituted.

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REPORT OF THE COMMITTEE ON SYNTHETIC DETERGENTS

To the Right Honourable Duncan Sandys, M.P., Minister of Housing and Local Government.

Sir,

I. INTRODUCTORY

Terms of reference, etc.

1. We were appointed by your predecessor on 12th May, 1953, as a Committee "to examine and report on the effects of the increasing use of synthetic detergents and to make any recommendations that seem desirable with particular reference to the functioning of the public health services". On 16th February, 1954, we presented an Interim Report.* Since then three of our original members—Lieut.-Colonel E. F. W. Mackenzie, Mr. R. Craig Wood, and Mr. H. Symon—have retired (on 10th May, 1954, 16th June, 1954, and 31st January, 1955, respectively); we take this opportunity of acknowledging their valuable help. We have met as a full Committee 17 times, and certain groups of our members and technical officers have met much more frequently. We have the honour of presenting the following final report.

2. As explained in our Interim Report, we found at the outset of our work that the use of synthetic detergents was causing concern in four different ways. There were fears that they might give rise to dermatitis and other dangers to health. There was some anxiety about their possible effect on domestic equipment and plumbing. There were suggestions that they were responsible for excessive foaming, and possibly reduced operational efficiency, at a number of sewage works. And there was in consequence concern about the purity of the rivers, including some used as sources of public water supply, into which the effluents from sewage works are discharged. We assumed that our function was to assess the nature, magnitude and implications of these problems as they appear to exist at present, and to recommend the lines on which they should be dealt with by the permanent bodies specially concerned. Our report should therefore be regarded as offering a survey, rather than as an attempt to provide final solutions.

The nature of our investigations

3. We decided not to take evidence formally and in public. Instead we took full advantage of the fact that individual members of the Committee, and the organisations with which they are associated (including your Department), had between them various means of access to all the chief sources of authoritative information on the subjects coming within our purview, as well as to the con-

* The Interim Report of the Committee on Synthetic Detergents. H.M.S.O. 1954.

siderable amount of literature that some of these subjects had already given rise to. The information thus gained was supplemented by replies to enquiries addressed on our behalf to a wide range of public and other bodies; by the results of investigations and experiments carried out at our request; and by the report of a tour of investigation in the United States made for us by one of our members, Mr. C. B. Townend, and an Inspector of your Ministry, Mr. A. W. Kenny. We are glad to record that in all these enquiries we met with a ready and helpful response.

4. Because of the very extensive and varied nature of our field of information we are not attempting to list all the individuals and bodies whose evidence, experience or advice we have taken into account. But we think it right—as in our Interim Report—to give some indication of their range. Through our own membership we have had the help of the Water Pollution Research Laboratory of the Department of Scientific and Industrial Research, the Ministries of Housing and Local Government, Health, and Agriculture, Fisheries and Food, the Department of Health for Scotland, the Department of the Government Chemist, the Metropolitan Water Board, the Middlesex County Council, the Croydon County Borough Council, and firms producing or using synthetic detergents on a large scale. We have been assisted in various ways, also, by such other organisations as the Medical Research Council and the British Association of Dermatology; the Building Research Station of the Department of Scientific and Industrial Research; the Institute of Sewage Purification; the Institution of Municipal Engineers; the London County Council; building and plumbing trade organisations; domestic equipment manufacturers; persons and bodies conducting research into the use of metals; and organisations representing local authorities, water undertakers, river conservancy authorities, and anglers. We have obtained written evidence—and often valuable help in the carrying out of experiments and observations—from over a hundred individual sewerage authorities and a number of statutory water undertakers. We have obtained evidence from the United Kingdom Scientific Mission in Washington on the effects of the use of synthetic detergents in the United States, and this was followed by a detailed report from our own delegation on their visits to forty-one American sewage works, three waterworks and seven research establishments. For the help given us by all these, and other organisations and individuals, we desire to make the warmest acknowledgments.

5. Of the mass of evidence we have collected in this way there is not much that is by itself final and conclusive. The matters with which we are concerned—whether synthetic detergents themselves, or the fields in which they appear to have noteworthy effects—are not fixed in nature or precise in form. Some of the evidence we have obtained may have only a local—or a temporary—significance. As will be shown, the amount and value of the experimental work it has been possible to get done specially for our purposes has been necessarily limited. The interpretation of such evidence as has been obtained has proved extremely difficult. It has therefore not been feasible to present a report consisting primarily of a comprehensive body of established facts that speak for themselves. Rather has it been necessary for us to note the existence, and assess as best we could the strength, of a large number of indications, and relate these to known facts and needs as we see them. For this reason our conclusions and recommendations envisage continued investigation into some of the matters with which we have dealt. Whatever immediate action is taken the need for

long-term observation of the effects of synthetic detergents should not be overlooked. We are not professing to say anything like the final word on a subject about which, by its very nature, finality is impossible.

The nature of some of the analytical evidence

6. One special difficulty attending our task must be mentioned at the outset—the lack of a long-established well-proven method for determining small concentrations, in sewage, effluents, and river water, of the surface-active material on which the most widely used synthetic detergents are based. In November, 1954, the Department of the Government Chemist, after an investigation of analytical procedures undertaken at our request, devised a modification of one of the methods earlier used, and found a material suitable as a reference standard, both of which we felt able to recommend to all those concerned with carrying out analyses of this kind. This revised method is described in Appendix A. Some of our information about surface-active material in sewage treatment plant, rivers, and waterworks, however, was collected earlier; the analytical procedures on which it was based are believed to have been less reliable. Indeed even our more recent information, based on use of the revised method we have recommended, cannot all be regarded as accurate within fine limits; there is still room for improvement on the method, and this is one of the directions in which continued research will be desirable. In making use of the figures reported to us we have had this difficulty well in mind; taken individually they cannot all be regarded as free from error.

7. The majority of us consider, nevertheless, that, studied together, the analytical figures available present a picture, for the purposes of our report, which we do not expect would be substantially altered as a result of improvement, however desirable for other purposes, in the analytical procedures used. We are satisfied that such variations as may exist in their accuracy do not affect the validity of the broad conclusions we have reached. Four of our number, on the other hand, are much less satisfied in this respect (more particularly as regards the lower concentrations of surface-active material in river waters and public water supplies), and therefore feel that much of the evidence should be read with considerable reservations. Insofar as these reservations are not generally reflected in the main body of our report they are mentioned specifically in our conclusions (para. 164).

The layout of this report

8. (*a*) In Section II (paras. 10 to 22) we describe what synthetic detergents are, what they are used for, and the way their manufacture and use have been developing.

(*b*) In Section III (paras. 23 to 37) we deal with the effects of synthetic detergents in the place of use—both on people who use them and those who drink tap-water containing residual traces, and on the plumbing and domestic appliances with which synthetic detergents may come in contact.

(*c*) In Section IV (paras. 38 to 103) we show what happens or may happen at sewage works as a result of the presence of synthetic detergents in sewage, and that some ingredients of synthetic detergents are getting through in the sewage effluents.

(*d*) In Section V (paras. 104 to 121) we explain what, in consequence, happens or may happen in rivers below sewage works outlets.

(*e*) In Section VI (paras. 122 to 139) we show how this may affect water undertakers using such rivers as their sources of supply.

(*f*) In Section VII (paras. 140 to 165) we discuss the implications of the effects on sewage treatment, rivers, and water purification, described in the three preceding sections.

(*g*) A summary of our conclusions and recommendations is set out in Section VIII (paras. 166 to 177).

9. The Appendices consist of a description of a revised method for determining the concentration of anionic surface-active material in sewage, sewage effluent, and water (Appendix A); a brief explanation of the differences in chemical composition between the three main classes of surface-active materials used in synthetic detergents (Appendix B); two photographs of foam at sewage works (Appendix D); and a guide to the technical literature in which detailed discussion and information about the behaviour and effects of synthetic detergents may be found (Appendix C).

II. THE NATURE, DEVELOPMENT, AND USES OF SYNTHETIC DETERGENT PRODUCTS

Composition of synthetic detergents

10. A detergent is defined in the dictionary as a washing or cleaning material, and detergents include soaps and products based on soap. Synthetic detergents are in practice commonly understood to mean those *soapless* washing products that have recently come into wide use, particularly for domestic purposes. They have the outstanding characteristic of not forming insoluble lime salts (curd or scum) when used in hard water. They are sold in powder, paste or liquid form, and are made up of many different materials and combinations of materials, consisting nearly always, however, of:—

(*a*) surface-active materials (organic compounds having wetting, dispersing and emulsifying properties), together with

(*b*) ancillary materials known as "builders", which in various ways make the compounded products more suitable for their intended uses.

The bulk of the synthetic detergents sold today are in the form of household washing powders, and these contain a greater weight of "builders" than of surface-active material. Among the various kinds of non-powder synthetic detergents—particularly those used for industrial purposes—the proportion of "builders" to surface-active materials varies widely. In some products no "builders" are incorporated at all. Where the term "synthetic detergents" is used in this report it usually relates to preparations in which surface-active materials and "builders" are present together.

Surface-active materials

11. Most of the surface-active materials (often described as surface-active agents) used in synthetic detergents are of basically similar chemical structure, in that they possess a hydrophobic (water-repellent) hydrocarbon group, with at least one hydrophilic (water-attractive) group attached. They can be arranged in three main classes—anionic, cationic and non-ionic. The nature of the three

classes and the differences between them are described in more detail in Appendix B. It is estimated that 95 per cent, by weight, of the surface-active agents at present used in synthetic detergents in this country are of the anionic class—they are the basis for nearly all the synthetic detergents sold for domestic use. Virtually all the other 5 per cent are non-ionics. Cationic surface-active agents are used in small quantities for their special bactericidal properties, but they are not satisfactory washing agents and are not used in household washing products.

12. Few, if any, of the surface-active agents used in the commonly sold detergents are in the chemical sense single substances. They consist of a mixture of several closely allied materials, the proportions of which may vary from batch to batch, although one may predominate; accordingly they are not easily susceptible to precise definition. But the total amount of active material can be determined and expressed as an equivalent amount of some standard substance.

"Builders"

13. The nature of the "builders" used with these agents (many of them are present also in domestic soap powders) varies with the uses to which the products are to be put. The main ones at present used are carbonates and silicates; complex phosphates; perborates or percarbonates; carboxymethylcellulose; and organic amides. Sodium sulphate formed during the process of manufacture is also present in most synthetic detergent powders, where it acts simply as a diluent.

Developments in synthetic detergent manufacture and usage

General

14. Impetus was given to the development of modern synthetic detergents in Germany during the first world war, in consequence of the severe shortage of natural fats and hence of soaps. Sulphonated products, with good detergent and wetting properties, were developed from materials based on coal tar. Later a number of products were prepared by the sulphation of fatty alcohols derived from animal and vegetable oils. Because of their cost and technical limitations the use of these early products was restricted to certain operations in the textile industry, but by the early nineteen thirties it had extended to the manufacture of shampoos and of products for special domestic uses. Subsequently new products were developed—sulphated secondary alcohols derived from a petroleum base. Both these and some of the sulphated fatty alcohols are still in use for a number of purposes for which their special properties are valuable. However, the large-scale production of domestic synthetic detergent powders since the second world war has followed on the development together of new types of surface-active agents and "builders". In little more than ten years synthetic detergents have captured over half the total detergent market in the United States, and development in the United Kingdom is not very far behind. They have been found highly suitable for most washing and cleaning purposes, and in hard water they have a definite advantage over soap products in that they do not form insoluble compounds with the calcium and magnesium salts to which hardness in water is due.

15. The growth of the use of synthetic detergents in this country since 1949 is shown in the following table, in which the figures are of actual consumption in the United Kingdom of the surface-active agents on which synthetic detergents are based:—

	Domestic (thousands of tons of active material)	Industrial (thousands of tons of active material)	Total (thousands of tons of active material)
1949	10·5	2·5	13·0
1950	12·5	2·7	15·2
1951	14·0	3·8	17·8
1952	21·0	5·2	26·2
1953	29·0	6·0	35·0
1954	33·0	6·0	39·0
1955 (estimated)	33·5	6·5	40·0

Consumption of the "builders" normally incorporated with these surface-active agents has gone up commensurately. From experience in the United States, and assuming that living standards will continue to rise, it seems reasonable to expect that growth in the consumption of synthetic detergents in this country will continue. It should be noted, however, that in the view of leading manufacturers it is unlikely that the future rate of growth will be as great as between 1951 and 1954. They believe that consumers in general have now largely determined their choice as between synthetic detergents and soap products, and that future increases in synthetic detergent consumption are more likely to arise from growth in population, and in the per capita consumption of washing products of all kinds, than from a further large-scale transfer of consumption from soap products to synthetic detergents. The history of the soap trade indicates, in their view, that growth in the per capita consumption of washing products takes place only slowly and over a long period.

Domestic uses

16. For certain purposes, particularly for personal use, a washing product in solid bar or tablet form is preferable, and in this respect soap is universally favoured. It has not yet been possible to produce a generally acceptable synthetic detergent bar. For other domestic purposes, however, synthetic detergents are now used widely. Surveys have shown that about three-quarters of all housewives in this country now use them regularly for one purpose or another; excluding hard household soap, toilet soap, and scouring powders, synthetic detergent preparations comprise slightly more than half the total sale, by weight, of products for domestic washing. The chief use is for the household wash, particularly iu hard water areas where soap products are partly wasted in eliminating the hardness, and deposit a scum that makes rinsing more difficult and can have various other disadvantages such as gradual discoloration of fabrics. Synthetic detergents have also proved generally acceptable for dish-washing, for which the alternative washing products are not only soaps and soap powders but also washing soda, ammonia and other alkaline preparations; the cleansing of dishes is improved both by the absence of scum and by the excellent grease-emulsifying properties of the surface-active agents. They are also used for many other household cleaning purposes, for substantially the same reasons as those already mentioned. Most household scouring powders now contain a synthetic ingredient in place of the soap used formerly. The total amount of synthetic detergents used for general household cleaning is less, however, than that used for other domestic purposes.

Non-domestic uses

17. Synthetic detergents are employed to an increasing extent in industrial processes, where they offer a number of technical advantages, including lack of scum formation, dispersal of scum previously deposited, stability to acids, and stability in solution with certain sterilising agents. These and other distinctive

properties are also leading to the development of various new or improved industrial techniques, ranging from the simultaneous scouring and dyeing of hosiery goods to the production of foamed concrete. In particular in the textile industry (where their industrial application was first developed), synthetic detergents have a very wide variety of uses in all scouring operations, and in almost every other wet textile operation, including the processing of wool, cotton, silk and linen, and the man-made fibres, where the efficient wetting-out and penetration that the use of surface-active agents helps to secure are of special value. Other industrial fields in which synthetic detergents have widespread application are in the fur, leather, paint, paper, rubber, pottery and concrete industries, the preparation of cosmetics, toothpastes and shampoos, the degreasing, plating, pickling and enamelling of metals, and the suppression of industrial dust.

18. Synthetic detergents are also employed in commercial laundries—though the total tonnage used in this field is still small compared with that of soap products. They have been found particularly useful in the low temperature washing of silks, woollens, and coloured goods.

19. For general cleaning operations in industry, commerce, and public institutions, synthetic detergents are used extensively—and also for meeting a number of special cleaning problems such as those arising in the dairying, milk processing, brewing, confectionery, and food industries.

Use with hard water

20. As mentioned above, synthetic detergents when used in hard water do not form a curd or scum. The 1949 Report of the Water Softening Sub-Committee of the Central Advisory Water Committee (which examined the question of softening of public water supplies before delivery to the consumer) accepted that, in areas where the tap-water is hard, some economic loss must arise from the use of soap, as part of the soap is wasted in the formation of curd or scum, which in turn may reduce the useful life of the washed clothes. The Report suggested that, to the extent that synthetic detergents became more widely used, hardness in water would be of diminishing significance in washing processes; the case for the softening of water by public water supply undertakers would then rest increasingly on the advantages of reducing scale formation in pipes, boilers, etc., and if synthetic detergents replaced soap entirely the question would arise how far softening by public water supply undertakers would be economic. Synthetic detergents have *not* replaced soap entirely in the six years since the Water Softening Sub-Committee reported, and we do not suggest that the provision and operation of softening plant by water undertakers in hard water areas is no longer worth considering. When softening schemes are being proposed, however, it will, we think, be desirable to bear in mind that for washing operations (particularly in the home) the increasing use of synthetic detergents has by now significantly reduced the disadvantages of a water supply that is hard.

The synthetic detergents nowadays mainly used

21. As mentioned in para. 11, about 95 per cent of the synthetic detergents sold in the United Kingdom are based on surface-active agents of the anionic class. The table in para. 15 also shows that over 80 per cent, by weight, of the surface-active agents incorporated in synthetic detergents consumed in the United Kingdom are marketed in preparations used in the home. For these

reasons—and for other reasons to be made clear later in this report—our study has been largely confined to the effects of household synthetic detergents based on anionic surface-active agents. The bulk of these are packaged preparations in powder form, consisting of surface-active agents (either alkylarylsulphonates or secondary alkyl sulphates) together with a complexity of "builders". While the formulations of the different brands of powder are broadly similar, in that they usually contain the same general types of ingredient, the proportion of the different ingredients may vary quite considerably. Moreover, as explained in the next paragraph, formulations may change as new materials become available. In general, however, rather more than half the total weight of a packet of synthetic detergent is accounted for by the surface-active agents and phosphates. The remaiuder consists of the other "builders" and diluents (including moisture) which are present in varying quantities. The total weight of surface-active agents used annually in domestic synthetic detergents in this country at present is estimated at about 33·5 thousand tons expressed as 100 per cent active material (see para. 15). The total weight of phosphates expressed as P_2O_5* is estimated at 29 to 30 thousand tons. The other "builders" are used in much smaller quantities.

Changes in synthetic detergent formulation

22. It is important to remember, however, that changes in mauufacturing technique, raw material supplies, or consumer needs, and the natural constant endeavour to make more efficient and acceptable products, may cause changes from time to time in the formulation of the synthetic detergents in most common use. Such changes have already occurred. An outstanding example is the change that has taken place in the type of anionic surface-active agent on which most household synthetic detergents are based. In the early post-war years, when synthetic detergents were still not in very extensive use, the most widely employed surface-active agent was one of the secondary alkyl sulphate type. This particular material is still used for certain purposes, but the big increase that has since occurred in household synthetic detergent usage followed the introduction of new and improved powdered products based on different surface-active materials, of the alkylarylsulphonate type; these new products form the bulk of the now much greater volume of household synthetic detergents sold. Further changes—in the nature of the "builders", as well as of the surface-active agents—may occur in the future; it cannot be assumed that the end of all development in this field has been reached. This must always be borne in mind when the effects of the use of synthetic detergents, as indicated by evidence gathered over a particular period, are being considered.

III. EFFECTS OF SYNTHETIC DETERGENTS AT THE PLACE OF USE

Toxicity to the skin

23. At the time of our appointment, we knew of the fears expressed in several quarters that the use of synthetic detergents might give rise to dermatitis. Cases

* Phosphate concentration is expressed as P_2O_5 in this section and in the section on sewage treatment, in accordance with common practice in the synthetic detergent industry and in sewage chemistry. In other parts of the report it may be expressed as PO_4. One unit expressed as P_2O_5 is equivalent to approximately 1·3 units expressed as PO_4.

of dermatitis following the use of these products have indeed been reported. But we have found, as stated in our Interim Report, that the incidence of skin trouble attributable to synthetic detergents is no higher than that previously due to the use of soap products, alkalis and allied preparations.

24. Obviously those chiefly subjected to the hazard are people engaged in housework and the staffs of laundries and catering establishments; in addition, some cases of dermatitis have been ascribed to contact with clothing laundered with synthetic detergent products. The opinion has been expressed by some authorities that the oils, fats and fatty acids of the skin, which act as a first line of defence against infection, may be affected by the defatting and drying properties possessed by synthetic detergents. This may give rise to a primary irritant dermatitis, or may lead to a sensitisation of the skin, resulting at a later date in an allergic dermatitis after further contact with these products. It is of some importance to note that eczema, old age, or poor circulation may specially predispose to this.

25. Enquiries made by the British Launderers' Research Association, however, have revealed that dermatitis is rare among commercial laundry workers and, further, that no significant increase has occurred since modern synthetic detergents were introduced. Similar investigations made by the Ministry of Health show that among the general population there has been some but no considerable incidence of cases, many of which may have been due to the use of unnecessarily strong detergent solutions. Information to this effect was received from the Ministry of Health's consultant dermatologist and from divisional offices in close touch with the work of general practitioners in various parts of the country. It is of interest also that in 1951, out of a total of just under 10,000 new patients seen at the skin departments of a London and of a provincial teaching hospital, only 143 were suffering from dermatitis attributed to the use of synthetic detergents. We have no reason to believe that there has been any increase in incidence since that time.

26. Moreover, British and American workers in the course of experiments on human and animal subjects have shown that synthetic detergents, though their effects in this respect may vary from one product to another, do not in general have marked irritant properties. This conclusion was reached by patch tests in which synthetic detergent solutions were applied on small pieces of lint kept in place on the skin for about five days; immersion tests in which an arm was submerged in detergent solutions for various periods; and experiments in which dilute aqueous solutions of synthetic detergent were applied to the shaven skins of rabbits and guinea-pigs.

27. The leading manufacturers of synthetic detergents have themselves carefully examined this question of dermatitis over a number of years. Their information is based not only on experiments of the kind described above, but also on the results of enquiries among consumers, and on observation of the incidence of skin-irritation among their own employees who have frequent and prolonged contact, in the normal course of their work, with synthetic detergents and synthetic detergent solutions, and who also take part from time to time in special tests. The conclusion reached by the manufacturers is that no abnormal incidence of dermatitis has arisen.

28. It is clear, then, from the evidence obtained from numerous sources that, though many of the synthetic detergents now in use can and do give rise to skin-irritation and dermatitis, more especially in predisposed persons, the

individuals so affected are few, and in all probability not more than those previously affected by using other kinds of washing product. No doubt the manufacturers will seek to reduce or even eliminate any possible harmful action of their products by further research and experiment; and individual users, both domestic and commercial, may be expected to avoid employing a particular product if they find it to act harshly on their skin. Users would be well advised, also, to avoid making up unnecessarily strong solutions, and in any event to rinse and dry the hands after the washing job is finished; in the case of some products a useful reminder to this effect is now printed on the container. People with unusually sensitive skins will no doubt choose the product best suited to themselves and will continue to use gloves, hand-creams and lotions.

Toxicity by ingestion

Acute toxicity

29. Few people are likely to eat or drink even a mouthful of synthetic detergent neat, or in a strong solution, except by a most unusual mischance. The only case reported to us (from the United States) where such a mischance had serious consequences related to a cationic detergent; cationics are bactericidal, and therefore need to be handled with care. The great majority of the synthetic detergents used in this country, however, are based on anionic (and, to a small extent, non-ionic) surface-active agents, and we have no evidence to show that these or the "builders" usually incorporated with them would, if swallowed by mistake, have serious effects. Moreover, most household synthetic detergents are sold as powders, and accidental swallowing of any sizeable quantity would be difficult. We therefore do not expect any material risk of acute toxicity by ingestion to arise from continued extensive use of these products.

Chronic toxicity

30. Much consideration has been given to the possible effects of repeated small doses of synthetic detergents (or of some of their ingredients) extending over a prolonged period. These doses may be taken in two ways:—

(*a*) by ingestion from imperfectly rinsed crockery, etc., that has been washed in synthetic detergent solutions; and

(*b*) by the consumption of water derived from rivers into which sewage effluents containing residual ingredients of synthetic detergents have been discharged upstream. The general question of the entry of these materials into some drinking-water supplies is dealt with more fully in a later section of this report.

31. An experiment with five commonly used synthetic detergents, in which cups were washed in the normal way and drained without rinsing, showed that sufficient detergent remained on the inner surfaces to produce, when the cups were refilled with tap-water, concentrations ranging from less than 0·2 to 1·0 parts per million of surface-active material. When, however, the cups were rinsed after washing, the concentrations were found to be less than 0·2 parts per million—a concentration no greater than that already apparently present in some tap-waters since synthetic detergents came into widespread use.

32. Enquiries as to the possible chronic toxicity of synthetic detergents have included experiments in which laboratory and domestic animals of various species have received, in their diet or water, various amounts of synthetic detergents over periods ranging from a few weeks to several years. From a study

of the relevant literature the conclusion has been reached that in most of the experiments no ill-effects were observed. (In a relatively small number there were some effects, such as gastric irritation or change of weight, but it must be emphasised that in all the experiments the animals received excessively high doses—sometimes as much as 1·25 gm. per kilogram body-weight per day; on a weight-for-weight basis this would represent, for an adult human being, a daily dosage of about 3 ounces of the retail product—a far higher daily dosage than could conceivably arise in practice.) Results of experimental work on similar lines undertaken by synthetic detergent manufacturers have led to the same general conclusions.

33. Apart from experiments on animals, there is a record of an investigator who took 1 gm. of sodium alkyl sulphate daily for eight weeks, and who also gave 0·2 gm. every two hours in the daytime to a series of gastric ulcer patients for seven months. In neither instance was any ill-effect observed.

34. Nevertheless, the possible occurrence of serious effects over a much longer term cannot be ignored, and in this connection we have had the advantage of the views of a Committee of the Medical Research Council under the chairmanship of Professor A. Haddow. No evidence exists that would justify our regarding synthetic detergents based on anionic or non-ionic surface-active agents as harmful in this respect, but as observations must be pursued over very long periods of time, and since it is not possible to argue with certainty from animal experiments to man, the possibility will need to be kept under careful review.

Effects on plumbing and household appliances

35. We drew attention in our Interim Report to the fact that where synthetic detergents are brought into contact with metal their excellent cleansing properties might, by removing films of grease or soap curd, either open up the possibility of corrosion or expose corrosion previously hidden. It seemed possible that sink and wash-basin outlets, traps, and waste pipes, might thus be affected—though no very widespread trouble had been reported earlier as a result of the already common use, for household cleaning, of soda and of bleaches containing chlorine, and these are known to be corrosive in certain circumstances. We have not, however, received any evidence to suggest that synthetic detergents are at present causing any serious trouble of this kind. We therefore think it necessary only to repeat the advice that the growing use of these new materials may well increase the importance of avoiding, in plumbing, both the use of easily corrodible metals and the use together of metals which are electrochemically dissimilar.

36. The only other effect on plumbing that has been brought to our notice arises from the propensity of most synthetic detergents to foam in water. Waste pipes and gullies of private dwellings usually provide conditions in which such foam is readily produced. The Building Research Station of the Department of Scientific and Industrial Research has collected reports of a number of instances, in this country and the United States, of foam backing up the waste pipes through the traps and into the dwellings on the lower floors of high blocks of flats. In two such instances the drainage of the building concerned was on the one-pipe system (i.e. soil and waste discharging together). Obviously, backing up of the drainage in such circumstances is particularly undesirable. All the other instances related to two-pipe systems; the foam which backed up into appliances—and sometimes overflowed—was therefore from sink wastes only.

There have also been reports of gullies, and drains leading to them, getting partly choked with residues of the foam that forms in them. Troubles of these kinds do not appear to be extensive or severe. But it does seem desirable for those concerned with the drainage of multi-storeyed dwellings to bear in mind that the difficulty can arise.

37. Household appliances that could conceivably be affected by contact with synthetic detergents are mainly those of metal construction, or with leather or rubber fitments, or with moving parts needing lubrication—e.g. washing machines. The cleansing action of the synthctic detergents might remove protective grease or oil and there might be some attack on metal surfaces. But not much trouble has in fact been reported. We know that the manufacturers of certain household appliances and synthetic detergents have adapted their products to minimise difficulty of this kiud. For any remaining difficulty the consumer has the remedy in his own hands—to exercise care, and if necessary not to use together the particular appliance and the particular washing product with which trouble is experienced.

IV. SYNTHETIC DETERGENTS AT SEWAGE WORKS

The concentration of synthetic detergents in sewage

38. In all towns, and in a growing number of rural areas, synthetic detergents after use in the home are discharged almost in their entirety into sewers. Those used industrially are discharged with the liquid wastes from the industry, and often these enter sewers also. Thus most of the synthetic detergents used in this country eventually arrive at local authority sewage disposal works.

39. The volume of sewage arriving at sewage works daily, in gallons per head of population, varies widely with the housing standards of the district, the habits of the population and the amount of industry. In some districts it amounts to more than 60 gallons, even in dry weather, but thc average figure for the country as a whole is about 35 gallons. During wet weather the volume is much increased when, as often happens, storm water is discharged to the same sewers as take the domestic flows. Ground water may also leak into the sewers.

40. With a population of about 50,000,000, and a yearly total consumptiou, in synthetic detergents, of 39,000 tons of surface-active material (as in 1954) the average concentration of surface-active material in sewage in dry weather would be about 14 parts per million. Of the "builders" entering the sewage with the surface-active material, the phosphates would be present at a concentration of, on average, 9 parts per million expressed as P_2O_5.* In any particular district the concentrations may be much higher or lower, according to the water usage per head and the popularity of synthetic detergents; they may also vary widely during the day, and may be expected to be much highcr on some days—e.g. washdays—than on others. It is thereforc not surprising that figures determined by analysis differ widely from place to place and from time to time.

* See footnote to page 8.

The practice of making regular determinations of the concentration of surface-active material in sewage has not yet become widespread. but such results as have been supplied to us are not inconsistent with the calculated figures.

Sewage and its treatment

41. Sewage is a complex mixture with water of solids and liquids of domestic and industrial origin. Its impurities are partly in suspension and partly in true or colloidal solution; it also contains vast numhers of bacteria. In the ahsence of oxygen it becomes "septic" and highly offensive in the course of a day or two. In the last century, when it was discharged to rivers without treatment, many of the rivers became foul and unfit for their normal uses. There is nowadays no disagreement with the view that the discharge of crude sewage into limited volumes of water is offensive, a menace to health and a gross misuse of water resources. Accordingly, sewage must always be purified where the body of water into which it is discharged is insufficient to prevent nuisance or danger to health. In practice this means in virtually all inland communities and in many situated on estuaries; the total population of the communities thus concerned in Great Britain amounts to about 36 millions.

42. Apart from preliminary treatment for the removal of large solids and grit, the purification of sewage can be roughly divided into two main stages—the removal of suspended matter (primary treatment), and the suhsequent removal by biological means of dissolved and colloidal organic matter (secondary treatment). At only a small and diminishing numher of sewage disposal works is purification limited to primary treatment alone.

(i) Sedimentation (primary treatment)

43. The suspended solids are largely removed hy passing the sewage slowly through large tanks in which the non-colloidal solids are settled out as a sludge. The sludge is later removed, hut its disposal need not concern us here.

(ii) Biological oxidation (secondary treatment)

44. The organic matter normally left in sewage after sedimentation is readily oxidised or otherwise converted into harmless substances hy the bacteria and other organisms present in the sewage itself. To enahle this process to proceed sufficiently rapidly, the bacteria must be brought into intimate contact with the sewage impurities in the presence of oxygen in such a way that the resulting solid products of reaction (which also contain most of the bacteria and other purifying organisms) can readily he separated from the liquid before the latter's final discharge, as purified effluent, to the stream. Apart from older methods that are now hut rarely used, there are two main means of purification, though each can be suhdivided according to the system of operation, the manner in which oxygen is supplied, and other matters of important detail.

Percolating Filters

This method of secondary treatment is used at sewage works serving ahout 22 millions of the population of Great Britain—including nearly all the smaller works. The sewage liquor from the sedimentation tanks is distributed over the surface of a hed of graded medium (stone, slag, clinker, coke, etc.) usually about 6 ft. deep. A gelatinous film containing hacteria and fungi forms on the surface of the medium, the open texture of which allows ready access of air, and purification takes place during the passage of the liquid downwards through it. The effluent from the filter contains particles of detached film

and other solid matter known as "humus", which is removed by further sedimentation.

Activated Sludge

This method of secondary treatment is at present used, or being installed, at sewage works serving a population in Great Britain of about 12 millions; the sewage works concerned usually serve fairly large communities. The sewage liquor after sedimentation is aerated in tanks, by compressed air or mechanical agitation, in the presence of "activated" sludge—a flocculent settleable sludge which gradually accumulates in these conditions—and the aeration of this mixed liquor is continued for several hours during which the impurities in the sewage undergo biological oxidation and the colloids become flocculated. The sludge is then separated from the purified sewage by settlement in final tanks, and a portion of it is returned to the aeration tanks to treat more sewage. The excess sludge which is continuously accumulating during the process is withdrawn for disposal elsewhere.

45. However complete the treatment of sewage, the final effluent is never entirely free from suspended and oxidisable matter. The aim must be, however, to reach a standard of purity at which the effluent can be discharged without nuisance or danger and, in particular, so as to satisfy the requirements of the River Board or of any other body or individual with a statutory or common law interest in the matter. Standards of purity for effluents could, of course, vary from one place—or even time—to another, according to local circumstances. Although at present the standards expected for most sewage effluent discharges to inland rivers are similar, there are instances where a lower standard is acceptable, and others where the requirements are more stringent, and there may be more variations in the future.

46. It will be apparent that the treatment of sewage results in the removal of two types of ingredient only—those that are insoluble and can be removed by sedimentation, and those that can be converted to harmless substances or incorporated in sludges during biological oxidation. Other ingredients, whether harmless or not, must pass as part of the effluent into the river. Generally, carbonaceous organic matter is converted to carbon dioxide and water, and the nitrogen of nitrogenous organic matter is converted to ammonia or—at the few works where the process goes far enough—to nitrate, both of which appear in the effluent. Simple mineral substances such as common salt are unaffected by the treatment.

How sewage treatment seemed to be affected when synthetic detergents first came in

47. When soaps, or products based on them, are used for washing purposes, the soapy water discharged becomes mixed with the much larger quantities of liquid in the sewers and reacts with the hardness-forming constituents of the water; the soap is almost always completely precipitated as a curd. A proportion of this settles in the sedimentation tanks at the sewage treatment works, the remainder being readily oxidised or removed during the later stages of sewage treatment. Thus the use of soaps never gave rise to any problem at sewage treatment works of sufficient capacity.

48. The surface-active agents used in synthetic detergents behave differently. As already noted, unlike soap they are not precipitated by hardness in water.

Hence when disposed of after use they will not be precipitated in the sewers, and are less likely than soap to be removed during sedimentation at sewage treatment works. This applies also to some of the "builders" incorporated in washing products with them. Thus some of the ingredients of synthetic detergents will still be present in the sewage flows passing to percolating filters or aeration tanks for biological oxidation. Realising this, many sewerage authorities began to watch, when synthetic detergents first came into wide use, for indications as to how their ingredients behaved. There were fears in some quarters that they might not be readily susceptible to the sewage treatment available, or that they might exercise adverse effects on the treatment processes.

49. During the earlier post-war years little was observed to support such fears; in this period household synthetic detergents, mostly based on a particular surface-active material of the secondary alkyl sulphate type, did not have a very extensive sale. From 1949 onwards, however, new household synthetic detergents based on different surface-active ingredients (of the alkylarylsulphonate type) were introduced; their sales were promoted vigorously and successfully district by district; and large numbers of people began to use them at about the same date. Almost immediately it was observed that the aeration tanks at a number of sewage works using the activated sludge process for secondary treatment became covered, sometimes to a depth of several feet, with a white persistent foam. A propensity to cause copious and persistent foam in the washtub was one of the leading characteristics of the new household products. The coincidence in time, between their introduction and the onset of foam at sewage works, left little room for doubt that the one was the cause of the other.

50. From then on conditions at most activated sludge plants tended to become worse. There were occasions when for short periods the foam diminished or even disappeared, but in general it became greater in quantity as the use of synthetic detergents grew—and apparently more stable, in that it persisted for longer periods after being blown away from the tanks. An idea of what this foam is like may be gained from the two photographs reproduced in Appendix D; they are only examples from a number we have received. It was also claimed that at certain works there was a loss of efficiency in the processes of biological oxidation. Further, the fact that the foam was reported at the very end of the purification process (indeed it was usually worst at that point) and to persist even into the streams receiving the effluent, suggested that some of the ingredients of synthetic detergents were passing right through the sewage works.

51. On percolating filter plants little foaming was reported, except at those works where effluent recirculation is practised (see para. 58). Conditions are not favourable for foaming on filters, since the liquid is not agitated with air. Nevertheless, effluents from percolating filters were in some instances seen to foam when they passed over a weir, and it seemed likely that in other respects synthetic detergents would behave in the same way in this kind of plant as in activated sludge plants.

Methods available for investigating effects on sewage treatment

52. Having received various reports of this kind, we made it our first task to try to establish the facts. As to the foam, it was there to be seen. But other statements, whether about suspected effects or suggested remedies, were not always fully authenticated. We therefore made wide enquiries and arranged for the carrying out of laboratory work, full-scale experiments and surveys.

Much of what follows is based on the results. In addition we have taken published work into account whenever it seemed relevant.

53. A word must first be said about the difficulties of establishing certain facts in connection with sewage treatment. In many other fields, to ascertain the effect of a particular constituent on a given process it is usual to carry out the process with and without that constituent, other conditions remaining identical, and to compare the results. It is impossible to achieve this fully when dealing with the treatment of sewage. To do so would involve operations at two identical sewage works with identical flows and loadings, and these do not, and in practice cannot, exist. We would also require one sewage containing, and another not containing, synthetic detergents; but synthetic detergents are nowadays so widely used that in the normal way they are present in all sewages. An alternative procedure, not ideal, is to use a single works that can be divided into two parts and to add synthetic detergents to the sewage fed to one part only. This method is open to criticism on the grounds that the synthetic detergents applied in this way are not present in the sewage in their normal state, namely, in association with the "dirt" from washing processes. A third possibility is to study the performance of certain small treatment works serving a population that can be controlled, so that the use of synthetic detergents could be permitted only during specific periods. Even this procedure is subject to the criticism that the purification plants might not have been acting with the same efficiency during the periods compared. There remain laboratory work, which can be kept under much stricter control but cannot precisely reproduce all the conditions at a sewage plant operating on a large scale, and pilot plant work, which more nearly simulates full-scale practice.

54. There is a further problem. Sewage is by no means of constant composition, but varies considerably in strength from day to day, because of changes in the weather, in trade effluents and in other factors. The treated effluent varies also. If considerable differences occur between two experimental periods, then to ascertain beyond reasonable doubt whether they are due to the factor under investigation or to other variables may involve repeating the observations many times. It is thus extremely difficult to establish small or even moderate effects with certainty; that is why some of our conclusions have to be based only on probabilities.

55. One special complication so far as anionic surface-active materials are concerned is the difficulty of determining accurately their concentration in sewage, sewage effluents, and river water. As explained in para. 6, not all the information we have obtained in this connection can be regarded as free from some degree of error, but the majority of us are satisfied that taken as a whole it is sufficiently reliable for our present purposes—particularly as regards the results obtained by use of the revised method of determination we have recommended.

Foam at sewage works

56. A general picture of the occurrence of foam on aeration tanks has already been given. We have obtained the following detailed account of its onset and development at the largest activated sludge plant in Britain, namely the Mogden Sewage Purification Works of the Middlesex County Council:—

> After the starting up period in December, 1935, the aeration tanks at the Mogden plant were completely free from foam for a continuous period of over 13 years.

Early in the morning of 31st March, 1949, the whole surface of the tanks became covered with white foam to a depth of about 6 inches, and it was learned that a new brand of household synthetic detergent had just been made generally available in the Middlesex area. During the following months the amount of foam increased considerably and at times accumulated to several feet in depth. However, it appeared to be readily dispersed by rain, and in periods of wet weather it disappeared entirely.

Early in July, 1950, the foam again increased considerably in volume and became noticeably "tougher"; it was lifted from the tanks by the wind in large pieces of perbaps 9 inches in diameter, which were unbroken after landing on a road or other surface. It was then learned that a new household detergent was being sold in the district.

For some years since then foam was continuously large in bulk and persistent in character; rain did not destroy it so readily, and only in times of exceptionally wet weather was dilution sufficient to prevent its formation. It was observed that sales promotion campaigns for household synthetic detergents were invariably followed by an exacerbation of the foam problem.

More recent experience has been variable; during one period of about ten weeks, from the beginning of February to the middle of April, 1954, tbe foam disappeared entirely, but during the following months it increased again, and in September, 1954, it was on occasion being blown for distances of several miles from the sewage works.

57. Judging from replies to a questionnaire we sent out to most of the other large activated sludge plants in this country, experience elsewhere has generally been similar. Foam was reported present in all but one of 38 works. It varied in intensity and was serious at 23 of them. Comments ranged from "excessive foaming but no particular trouble" to "at times it builds up to a depth of over 10 feet".

58. Of 44 works using percolating filters, some foaming was reported from 33, the comments ranging from "slight traces in final tanks" to "frequent occasions when the foam is 4–6 feet deep". Foaming has also been reported where filter effluent is pumped back to the filter inlet, as in some modern works; five out of nine such works had excessive foaming at this point, though the operation of the plants did not appear to be seriously affected.

59. Foam at sewage treatment works is mainly a nuisance, but it is also a source of danger. In excessive quantities it may make it impossible for maintenance staff to walk along footways between the tanks as is necessary to carry out their duties, and on collapsing it leaves a residue that is slippery underfoot. Where it spills over on to surrounding land it leaves a similar unpleasant residue that kills grass and plants, and makes the sewage works—which can be attractive—unsightly, dirty and malodorous. When blown away from the works it may cause nuisance where it lands, and as it contains sewage matter it may be a danger to public health. It certainly gives rise to complaint, and in our opinion rightly so. We consider that its continued production at sewage works should not be tolerated indefinitely.

60. In para. 49 we described the coincidence in time between tbe onset of foam at sewage works and the introduction of the present kinds of household synthetic detergents. It is true that foam was on occasion experienced at some sewage works before synthetic detergents became generally available. Its occurrence

was exceptional, however, and rarely indeed was it either so considerable or so persistent as to give rise to any difficulty in operating the plant. Nowadays it occurs widely—not only in Great Britain but also in the United States, Germany and other countries where synthetic detergents are used and sewage treatment is practised. We know of no satisfactory explanation to account for its onset and continuance over such a wide area, other than the rapid growth in the use of synthetic detergents of the present type.

61. We have thought it reasonable to assume that these synthetic detergents would not cause foaming at sewage works if they were not so made as to produce copious and persistent foam in the washtub. We have therefore enquired whether it would be realistic to hope that, at some time in the future, household synthetic detergents might be changed in composition so as not to possess this property. The advice we have received from leading manufacturers of household washing products is that housewives in general regard foam as an important attribute of detergents, and find it of considerable value as an indicator, during the washing process, of the adequacy of the washing solution. When the foam drops it is a sign that more detergent is needed or that a fresh solution should be used. Certainly the sale of non-foaming products is small compared with that of the foaming products. They appear to be acceptable for some purposes, particularly in the United States for use in washing-machines of the kind that do not operate satisfactorily with foaming products, or which work sufficiently automatically to dispense with the need for foam as an indicator. But in the view of the leading manufacturers, non-foaming products would not be generally acceptable for household use.

Control of foam at sewage works

62. In the period since this problem of synthetic detergent foaming at sewage works began to be serious, a number of sewerage authorities here and abroad have been trying out methods for its control. As early as the end of 1953 attempts in this direction had been made at 18 of the 38 activated sludge plants in Great Britain to which we had addressed specific enquiries. The possible methods which have been considered, in this country and abroad, and the extent to which they seem to offer a solution to the problem, are discussed below.

Spraying

63. Drops of water falling on foam in activated sludge tanks tend to break it. Their efficacy in this respect depends a great deal on their size and velocity at the point of impact. It also depends on the character of the foam; the synthetic detergents used in earlier years produced foam which broke up readily under spraying, but the foam occurring at many sewage works nowadays appears to be more resistant. Several works have used spraying with water or purified effluent as a temporary expedient, with different degrees of success. It has given more satisfaction where the foam is produced either intermittently or in only small volume, and has been less successful where the build-up of foam is continuous and heavy.

64. At most sewage works the amount of water needed to control present-day foam adequately by the spraying method would probably be considerable—perhaps as much as 10 per cent of the total sewage flow. It would seldom be practicable or desirable to obtain this volume of water from the public supply: even if the quantity needed were available, the cost of purchasing and getting it to the sewage works would certainly be very heavy. A more obvious source of

water for this purpose is the purified sewage effluent itself. But its use for spraying aeration tanks would require the installation of special pumps, pipelines, and jets. The cost of adopting such a method would vary from one plant to another; in 1953 it was estimated that at Mogden it would be about £15,000 a year, including depreciation on £20,000 worth of capital works. As explained in para. 22, however, the formulation of synthetic detergents cannot be expected to remain always the same; nor, therefore, can the incidence or nature of sewage works foaming. Spraying arrangements installed to control present-day foaming might prove to be either unnecessary or unsuitable in quite a short time. For this reason, as well as for general reasons to be mentioned later, we are not disposed to regard spraying as the real answer—at least at this stage—to the problem of synthetic detergent foaming at sewage works. We have no doubt, however, that it could be useful at some works in the absence of a better solution of the difficulty.

Defoamants

65. A method of foam suppression which, especially as it involves virtually no capital expenditure, seems at first sight more attractive, is the use of chemical defoamants. Several types have been suggested in this connection. Cationic detergents could themselves act as defoamants, but their use must be ruled out on the score of expense, and also because their bactericidal properties could be expected to interfere with biological processes in the sewage works and possibly in the receiving stream. It seems likely that silicones, though not bactericidal, would have to be ruled out for similar reasons. The most promising defoamants are those based on petroleum oils, some of which are in use at certain sewage works in America and at least one large works in this country. The experience at these works suggests that they may be effective at concentrations of 2 or 3 parts per million of the sewage flow, and at a cost which though considerable would not necessarily be prohibitive—particularly at works where foaming is not continuously heavy. They could be used either as the sole means of foam control, or—as at some works in the United States—in conjunction with the use of water sprays.

66. It is not known, however, whether even these defoamants can be destroyed during the sewage purification processes or prevented from passing with the sewage effluent into the receiving river. Nor is it known to what extent, if they do enter the river, they have any deleterious effect on the river water. Few sewerage authorities are in a position to take the risks which large-scale trials in this connection would involve. Some experimental work is now being carried out, however, and the results will merit careful study. Meanwhile we do not feel justified in recommending the use of chemical defoamants as a means of foam suppression at sewage works generally.

Adjustment of operation of aeration tanks

67. In the washtub, synthetic detergent foam dies down when the water has become very dirty—that is, when the water has a high content of suspended solids. We received reports, at an early stage in our investigations, suggesting that a somewhat analogous though much more complex effect was being or could be substantially achieved at a number of sewage works, particularly in the United States, by the practice of increasing the content of suspended solids (activated sludge) in the aeration tanks, beyond what would otherwise be considered necessary or desirable in normal operation. We thought it necessary to investigate this question very carefully. Our represeutatives made detailed

enquiries about experience in the United States, and we obtained the co-operation of the superintendents of five large activated sludge plants in Great Britain in the carrying out of large-scale tests addressed to this specific point.

68. Our enquiries showed that, on the whole, foaming on aeration tanks was not so severe in the United States as here. This appeared to be due in part to the fact that in most American cities the water consumption per head is higher, and the concentration of synthetic detergents in sewage is in consequence lower, than in Great Britain. It was reported also, however, that American sewage works operators did try to keep the solids concentration in the aeration tanks as high as possible, and that some reduction of foaming had been obtained where this was done. But the physical limitations of plant prevented a general application of this method. These limitations are of two kinds and appear to exist in this country at least as much as in the United States: pumping and pipe-line capacity, and capacity for adequate oxygenation of the sewage.

69. The first limitation relates to the rate at which sludge can be removed from the final tanks—from which more sludge has to be removed if an increase in the concentration of solids in the aeration tanks is to be maintained. In general the installed capacity of pipelines and pumps at sewage works is designed to maintain in the aeration tanks the concentration of solids necessary for the actual purification of the sewage to normal standards, and though it will usually have some margin it is unlikely to be sufficient to provide for the materially higher concentration of solids which would appear to be needed for a significant degree of reduction of synthetic detergent foam. At many works, therefore, the attempt to prevent or reduce foaming by this method would not only involve increased pumping costs but would also require plant reconstruction—on a scale that would differ from one plant to another according to the nature and operational requirements of the existing installation.

70. The second limitation relates to the primary need to ensure that at all times the oxygen demand of the mixed liquor in the aeration tanks is satisfied. This oxygen demand increases with any increase in the concentration of solids. But the supply of oxygen (whether by air blowing or mechanical agitation) is limited by the capacity and design of the available plant. In most works this will have been installed with the object of meeting the oxygen demand of the mixed liquor at the concentration of solids necessary for the normal processes of purification; here again any marginal capacity available is unlikely to be very considerable. If the concentration of solids is increased without a corresponding increase in the oxygen supply, purification is likely to suffer. In this respect too, therefore, any attempt to avoid or reduce foaming on aeration tanks by increasing the concentration of solids would at many sewage works require not only an increased consumption of power but also the extension or reconstruction of sections of the plant.

71. In spite of these limitations, however, it did appear advisable to determine whether or not working with a high solids content in aeration tanks under the conditions usual in this country could prevent excessive foam production. To this end we arranged trials at five works. We asked those concerned to do all they could by way of increasing solids, even to go beyond the bounds of general practicability by concentrating the solids into one section only of the aeration plant, and if necessary taking the risk of discharging some solids with the final effluent.

72. These trials were carried out very thoroughly and the results were supplied to us in considerable detail. Briefly, at four of the works it was possible to isolate a section of the plant, and to increase the concentration of solids in the aeration tanks in that section while as far as possible maintaining concentrations of the normal level in the aeration tanks in other sections of the plant. This enabled a direct comparison to be made between the foaming on the experimentally operated section and on the normally operated sections. At two of the four works there was no difference. At the other two, a slight reduction of foaming was noted in the experimental sections, but the foam was still a nuisance. In these experiments the concentration of solids was taken to more than double the normal value—to a point, indeed, where the quality of the effluent suffered. The results at the fifth works, where the solids were increased in all the aeration tanks, were complicated by the fact that during the experiment a marked increase occurred in the consumption of synthetic detergents locally, after special promotion of two household products; considerable foaming occurred even with the highest concentration of suspended solids.

73. The fact remains that at certain plants, particularly in the United States, the activated sludge itself does seem to play a part in the suppression of aeration tank foam. There is growing evidence, however, to suggest that its effectiveness in this regard depends as much on the character or quality of the sludge as on its concentration. As explained in para. 46, at most sewage works the nitrogenous organic matter in sewage is converted to ammonia but not oxidised to nitrate. But at those works which do take purification to the nitrification stage, the sludge produced is much denser and more active, and it seems that this, besides making it easier for a high solids concentration to be maintained, may have an important bearing on its capacity to prevent foam. In recent experimental work at Mogden, where the load on one section of the plant was restricted so as to enable purification to be taken to the nitrification stage, foam on that section was reduced to negligible proportions at a moderate solids concentration; on the rest of the plant, where the nitrification stage was not reached, foam remained considerable even though the concentration of solids was more than twice as high. At the Maple Lodge works of the Colne Valley Sewerage Board the aeration tanks remained free of foam for several years while nitrification was being achieved; during a few months in 1955 when it proved impossible to maintain nitrification, foaming occurred; later in 1955 nitrification was restored, and foaming ceased. At certain sewage works in the United States where the maintenance of a high concentration of solids in the aeration tanks was reported to be accompanied by freedom from excessive foam, it was noted also that purification was being carried to the nitrification stage. It seems likely, therefore, that the problem of synthetic detergent foaming at sewage works using the activated sludge process would be very much easier to solve if the purification processes at those works were prolonged to the point of producing a nitrified effluent. Such an extension of the purification processes would not normally be possible, however, without considerable extensions to the aeration and detention tank capacity.

Alterations or extensions to sewage treatment plant

74. In so far as certain of the above-mentioned possible methods for controlling foam seem likely to be of limited efficacy, at many works, because of limitations in the layout and capacity of the existing plant, it might be thought that the answer to the foam problem should in these cases be sought by extending or

reconstructing the works—or, at least, where new works are in any event necessary, by incorporating in the constructional and operational plans arrangements specially designed to assist in the control of synthetic detergent foaming. As mentioned in para. 64, however, we are not inclined to recommend widespread public expenditure, at this stage at least, on capital works needed solely to meet a foaming problem that may change in its nature or incidence with changes in the pattern of synthetic detergent production—particularly as it is by no means clear that, even if there were no such changes, foaming at sewage works could always be completely and safely eliminated by the means suggested. A further objection to capital expenditure for this purpose is explained below.

Conclusions on the problem of foam at sewage works

75. We have said that the continued production of foam at most activated sludge plants, and to a lesser degree at certain percolating filter plants, should not be tolerated indefinitely. It seems that at some works methods have been or could be adopted which would assist materially in suppressing or avoiding the foam nuisance there, while at many other works the task of finding an effective and safe solution can be neither easy nor cheap. The various possible methods need to be kept in mind, and further investigated; at certain works such investigations are indeed already in train. Where a remedy or useful palliative is found to be practicable without undue risk or expense, it should of course be applied. It is important to remember, however, that this question of foaming at sewage works should not be considered in isolation. As will be explained later in this report, some of the surface-active materials on which the most widely used household synthetic detergents are based are passing through sewage works and into rivers, and are thereby giving rise to certain anxieties, irrespective of whether foam occurs, or is suppressed, on the sewage works itself. In many instances, therefore, steps taken—perhaps with considerable difficulty and public expense—merely to ensure that foam occurring at sewage works is kept down would, however successful, be dealing with only a part of the problem—and not necessarily the most important part. In a later section of the report we draw attention to the fact that if the surface-active agents incorporated in synthetic detergents could be made to respond more readily to biological oxidation during sewage treatment many of the present causes for anxiety about the effects of their presence in sewage would disappear. Probably one of the problems which would thus disappear would be that of foaming at sewage works, since it is unlikely that foam would continue to be produced on aeration tanks to anything like the present extent if the surface-active materials entering the tanks in the sewage became rapidly decomposed or inactivated by the treatment processes. We consider that so long as there is a reasonable prospect of this position being reached (and we recommend, later in the report, that for a number of reasons it should be aimed at) it would be inadvisable for sewerage authorities in general to incur any substantial capital expenditure on measures designed solely for the suppression of foaming.

76. We have discussed foam at considerable length, because at the works where it occurs it is the most obvious and perhaps the most immediate of the problems set by the presence of synthetic detergents in sewage. But as already stated it is not necessarily the most serious. Whether foam occurs—or is suppressed—or not, there is the question of the extent to which synthetic detergent residues persist through sewage treatment, and of the effects which they may have on the treatment processes and in rivers and waterworks downstream.

The extent to which the surface-active materials in synthetic detergents persist through sewage works and into the effluents

77. Normally, polluting matter in sewage is either removed after settling out with sludge at various stages of treatment, or converted to innocuous substances by biological oxidation. This is what happens, for example, with soap residues. It seems clear that these processes also operated successfully with regard to the surface-active ingredient used in most of the synthetic detergents sold in Great Britain, on a relatively modest scale, some years ago—a secondary alkyl sulphate. It is not yet clear whether all secondary alkyl sulphates are readily eliminated during sewage treatment, but in the case of the particular product referred to the matter has been demonstrated fairly conclusively. The observations and experiments on which this view is based include an experiment in which some of this product was added to half the sewage received at a sewage works divided into two identical units; when the effluents from the two units were compared it was found that almost all the added surface-active material had been eliminated. Although this material can cause certain difficulties in sewage treatment when at excessive concentrations, at concentrations corresponding with the present normal surface-active content of sewage in this country it is almost completely disposed of by sedimentation followed by biological oxidation.

78. However, the great expansion in the past few years in the consumption of synthetic detergents has been of products based on surface-active agents of another kind—the use of which has by now outstripped fourfold that of the secondary alkyl sulphates mentioned above. These more widely used materials are of the alkylarylsulphonate type, and appear to be more difficult to break down or eliminate entirely during sewage purification. It is not yet known whether this is equally true of all alkylarylsulphonates, but the evidence strongly suggests that it does apply to the kinds mainly used in this country during the last few years. This is not merely an inference from the persistence of foam, at a number of sewage works, right to the end of purification; it is established by the presence of surface-active materials at significant concentrations in sewage effluents. It is known that the relatively small quantity of secondary alkyl sulphates in sewage is virtually eliminated during treatment; it is known that the predominating surface-active materials in sewage nowadays are the alkylarylsulphonates referred to; and it has been shown by analysis at a wide range of works that surface-active material is present in sewage effluents at concentrations often as high as a half, and sometimes more, of the concentrations in the crude sewage.

79. It is to be expected that in so far as a proportion of this surface-active material does not persist during sewage treatment, some of its elimination will take place during the primary or sedimentation stage. The affinity of active material for grease and dirt, which is so valuable a property in washing processes, should cause some of it to adhere to the settled sludge in the sedimentation tanks. This has been confirmed by analysis. In 1955 a representative selection of sewerage authorities were asked to carry out frequent and regular analyses over a prescribed period by the method described in Appendix A, to show the extent to which surface-active materials were in fact being removed from the sewage flow at their works by the various stages of treatment. By the end of July, 1955, reports had been received from twelve works. They showed that at each works the degree of removal of surface-active material during sedimentation

varied from time to time, but the average for all twelve works was about fifteen per cent—seven of these showing a smaller average degree of removal, and five a higher degree, the highest being slightly less than one-third. Very seldom did even isolated analyses show removal of more than one-third. At two of the works the exercise was repeated at a later period of the year. The results were about the same.

80. The breakdown or removal of any substance during the second main stage of sewage treatment (the biological stage) depends on the existence and growth of bacteria or other organisms that can utilise it as a source of food, or upon the production, during the process, of surfaces upon which it can be adsorbed. Most if not all natural organic substances can be destroyed by bacteria, and bacteria will also attack some organic compounds that so far as is known are not produced in nature. Frequently a biological filter, or an activated sludge, has no significant action on these substances at first, but ultimately a suitable bacterial flora develops, after which oxidation takes place quickly and reliably. Such a system is said to have become acclimatised. It is significant that synthetic detergents of the present type have been present in sewage in this country for several years, and yet reports from all parts of the country have shown that surface-active materials which must derive from them are still being discharged with sewage effluents. It therefore seems that sewage treatment systems have not become acclimatised to these products after several years. Reports from abroad confirm this impression.

81. It is not a matter of only a small proportion of these materials getting through. As stated in para. 78, the concentration of surface-active material still remaining in sewage effluent after biological oxidation is often as much as half, or more, of that in the crude sewage. At the Mogden works during 1954, for example, the concentration in the crude sewage averaged about 8 p.p.m., and that in the final effluent about 5 p.p.m. Between October 1954 and June 1955, at the same works, the average concentration in the final effluent, as measured by the recommended method described in Appendix A, was over 6 p.p.m. Even on an experimental unit at these works, in which purification was prolonged to the nitrification stage which can be attained at few existing works in this country, the average concentration in the final effluent was over 4 p.p.m. Reports showing a similarly limited degree of removal of surface-active material were received during 1953 and 1954 from a number of other sewage works where biological treatment is provided. In 1955 we asked selected sewerage authorities to report on this point again; they carried out a series of regular analyses using the recommended method. Ten authorities had sent in full reports by July. At three of the ten works the average concentrations reported in the final effluent were more than sixty per cent of those in the incoming sewage; at three works they were between fifty and sixty per cent; at three works they were between forty and fifty per cent; and at the one works where an average as low as twenty-six per cent was reported the basis of sampling was not comparable with that of the crude sewage. The average concentrations of surface-active material in the final effluents from the ten works ranged from 1 to 12 p.p.m., six of them lying between 3 p.p.m. and 6 p.p.m.

82. The only report we have received to the effect that biological treatment has under certain conditions appeared to decompose virtually all the surface-active content of a modern sewage was based on experiments at a sewage treatment plant in California serving 17 dwellings and the non-resident staff at a

nearby factory. This report was of interest primarily, however, because of the use of a new method of ascertaining the proportion of surface-active material removed during sewage treatment. This new method, using radioactive tracer technique, may be worthy of further and larger-scale trials.

83. The fact that a proportion, and only a proportion, of the surface-active material nowadays present in sewage remains in the effluent after biological treatment may imply that:—

(a) The alkylarylsulphonates at present used in most household synthetic detergents are not oxidised during sewage treatment at all, but some of them are adsorbed on the surface of biological filters or activated sludge—the capacity for adsorption being limited. In that event one would expect further adsorption to take place after the effluent has been discharged to a stream, particularly if the stream has a muddy bed and if algae and weeds proliferate in it.

(b) The alkylarylsulphonates referred to are not only adsorbed but are also oxidised, but so slowly that their destruction is not completed during the sewage treatment process. In this event also it would be expected that the purification process would continue in the receiving stream until eventually the materials were completely destroyed.

(c) The alkylarylsulphonates being mixtures and not single compounds, some of their constituents are much more readily and completely oxidised than others. In this event there might be little or no further elimination (other than by adsorption), in the receiving streams, of those constituents that do get into it.

More research is needed before it can be established which of these is the right explanation. What is already clear, however, is that widespread use of synthetic detergents based on alkylarylsulphonates of the kinds utilised in this country during the last few years has meant that surface-active materials derived from these products have been passing through sewage works into rivers in appreciable amounts.

84. So far we have referred to what happens at sewage works to the two commonly used types of surface-active material in the anionic class—nowadays about 95 per cent of the total sold. The fate, in sewage treatment, of the 5 per cent or so based on non-ionic surface-active materials has not been so fully examined—though one large-scale experiment is now in progress. From small-scale work, however, it seems that the non-ionics are attacked by biological agencies with difficulty, if at all.

The effect of the surface-active materials on sewage treatment processes

General

85. The previous section dealt with the fate, during sewage treatment, of the surface-active materials. We have also had to consider whether their presence in the sewage, besides bringing, in many cases, a foam nuisance which causes expense and difficulty to the operators, has any adverse effect on the actual treatment processes.

86. We have confined our attention to the general position in which sewage is purified by the processes already described. Accordingly we have not examined in detail the peculiar problems of the few sewage works where, because of the presence of large volumes of effluent containing grease from wool processing,

the sewage has to be treated with acid to crack the grease before it passes to the biological stage of purification. At these works the presence of a high content of synthetic detergents in the sewage could cause special difficulties, but they do not seem appropriate to consideration of the effects of synthetic detergents on the purification given at sewage works generally.

87. As regards sewage works generally there is as yet no conclusive "proof from experience". We have already given reasons why small or even moderate effects might not be discovered in the course of routine supervision, and—more particularly—why some such effects, even where detected, could not necessarily be attributed with confidence to the presence of any particular substance. Although, in reply to a questionnaire we sent out at an early stage in our investigations, a number of sewerage authorities expressed the view that synthetic detergents were responsible for a deterioration in the quality of the effluent being discharged from their works, no definite conclusion could be established from the records of the works concerned. In a number of cases the deterioration could have been due to the fact that the works were receiving a bigger sewage load than they were designed for, and that the extensions necessary to deal with it had not yet been completed. We have therefore sought evidence from experimental work.

Effect on sedimentation

88. It might at first sight be expected that, because of their suspending, dispersing, and emulsifying properties, the surface-active materials used in synthetic detergents would hamper the primary stage of sewage treatment—sedimentation. In practice, however, there is little evidence here or in the United States to suggest that at the concentrations at which any of these materials are normally present in sewage during sedimentation their special properties have any adverse effect.

Effect on biological oxidation

89. The efficiency of the biological oxidation stage of treatment depends partly on the rate at which the sewage is aerated. From certain work described later in this report (Section V) it appears that in clean water the presence of alkylarylsulphonates (of the kind most commonly used in household synthetic detergents in this country during the last few years) at concentrations of only a few parts per million in certain conditions reduces the rate at which the water dissolves oxygen. A similar if less marked effect has also been noted where the water contains sewage effluent. If a like effect occurs in sewage itself, during the biological oxidation process, there must be some retardation of purification wherever conditions are such that air supply is the limiting factor. The question whether these commonly used alkylarylsulphonates do in fact hamper sewage purification in this way clearly needs careful investigation (which should be extended to other kinds of surface-active agents also). Meanwhile there are some indications that, where they are present in sewage, a retardation of the biological oxidation process does—for whatever reason—occur.

90. One such indication comes from the Mogden works. At this works, from the time it commenced operation in 1935, a well-nitrified effluent was produced continuously until 1950. From that year, during a period of rapidly increasing usage of household synthetic detergents, the performance of the plant declined to the point at which nitrification could no longer be achieved. The load on the works increased also during this period, but reserve plant with adequate

additional capacity was brought into use; in spite of this, all efforts to restore the standard of effluent previously reached have failed. Accordingly an experiment was arranged in which one of the fifteen treatment units at the works was separated from the rest and operated independently. By substantially reducing the load on this unit it was found possible once again to produce a nitrified effluent. The load was then gradually increased again in order to determine the maximum which could be taken while still producing a well-nitrified effluent of the pre-1950 standard (of which comprehensive records had been maintained over many years). It was found that if it was to produce as good an effluent as was produced before 1950, the experimental unit could deal with only four-fifths of the pre-1950 load. It thus appeared that the present-day sewage at Mogden is less amenable to purification than the sewage received between 1935 and 1950; and it has been estimated that the capital cost of the extra plant which would be needed to restore the standard of purification then given would be about £600,000. Records of trade waste discharges in West Middlesex are unusually complete, and there was no known addition or change suddenly occurring around 1950 which would account for such a marked change in purification performance. On the other hand the change did coincide with the onset of foaming and other manifestations of the rapid increase in synthetic detergent consumption which followed the introduction of household powders based on alkylarylsulphonates.

91. A series of laboratory experiments carried out at another sewage works in Great Britain indicated that the addition to sewage of a commercial preparation incorporating these alkylarylsulphonates at a concentration of about 10 p.p.m. resulted in a 10 per cent reduction in the quality of effluent from percolating filters and from activated sludge. At yet another sewage works in Great Britain, a preparation based on these alkylarylsulphonates was applied to the sewage passing through one part of the works, and the effluent from this dosed sewage was found to be of slightly worse quality in most respects than the effluent from the sewage to which nothing had been added—treatment in both cases being by means of percolating filters. Experiments at the same works with activated sludge treatment did not show significant effects, but when similar work was done with activated sludge treatment on a pilot plant in Holland the presence of alkylarylsulphonates in the sewage appeared to retard purification noticeably.

92. Our delegation to the United States (where many household washing products have been based on similar kinds of alkylarylsulphonates to those used in the bulk of household synthetic detergents in this country) reported that there, too, though there was not much evidence that synthetic detergents affected sewage purification noticeably, such information as existed suggested that at the biological oxidation stage the influence was adverse. The question is still engaging the attention of a number of American investigators.

93. In an effort to secure further evidence we arranged for experiments to be carried out in Great Britain at two small sewage works serving institutions at which the use of synthetic detergents could be kept under strict control. At each, soap products only were used for one period, and for a second period all washing except personal washing was carried out entirely with synthetic detergents—based on alkylarylsulphonates. The effluent was in each case distinctly worse, on average, during the period when the synthetic detergents were being used. When the results were subjected to statistical analysis it was

found that they could not be described as significant, but this does not necessarily mean that the differences were not real—only that the odds against their being accidental were less than 20 to 1.

94. It will be noted that most of the evidence referred to so far about the effects of surface-active agents on sewage treatment has related only to alkylarylsulphonates—and only to the kind widely used in this country since 1950 (as to the possible effects of other kinds of alkylarylsulphonates there is as yet little information). The next most commonly used surface-active agent in this country is one of the secondary alkyl sulphate type. In the earlier post-war years when this particular agent was the basis for most household synthetic detergent products, no extensive sewage treatment trouble apparently attributable to synthetic detergents was reported. The total usage of synthetic detergents at that time was nothing like as large as that of present-day alkylarylsulphonate products. Nevertheless, the presumption that this particular kind of secondary alkyl sulphate (we have no evidence about other kinds) has no significant effect on the biological oxidation process is borne out by the results of specific experiments in the laboratory and at sewage works. It is also what might reasonably be expected from the fact that, as explained in para. 77, this particular material appears to be readily oxidised during sewage treatment and therefore does not persist through the treatment process.

95. Very little is known as yet about the possible effects of surface-active agents of the primary alkyl sulphate type, or of the cationic or non-ionic classes of agent—though the bactericidal cationic class are believed to be capable of having an adverse influence. Their total usage is likely to remain so small relatively, however, that we would not expect their presence in sewage to be of any significance in sewage treatment in practice.

96. The indications in paras. 89 to 93, relating to the effects of the alkylarylsulphonates in common use, are obviously the most important, as it is these agents that comprise the bulk of the surface-active material which has for some years been normally present in sewage. Taken singly, they cannot be regarded as conclusive. Taken together they make up quite a strong body of presumptive evidence—that the alkylarylsulphonates in question, in concentrations of an order now occurring, reduce the efficiency of biological oxidation plant at sewage works. Obviously this point needs further investigation.

97. In any case, however, it seems probable that any adverse effect that a surface-active material might in fact have on sewage treatment would be reduced or eliminated if the material were itself capable of being broken down during the purification process. This seems to us the most likely explanation for the fact that, of the two most commonly used surface-active materials we have discussed, the one which appears to be readily oxidisable (the secondary alkyl sulphate) appears also to have no adverse effect on sewage treatment, while the one which, as noted in paras. 78 to 83, seems more resistant to sewage treatment (the alkylarylsulphonate) also gives indications of retarding the treatment process. It is one (though not the most important) of the reasons why later in this report we recommend research towards achieving the position in which surface-active materials used in household synthetic detergents (whether of the alkylarylsulphonate type or of other types) can be made to respond to biological oxidation more readily than has been the case at sewage works in this country during the last few years. It is true that, other things being equal, easily oxidisable surface-

active materials (just like the soap products which synthetic detergents have to some extent replaced) must by definition make a bigger direct demand on the purification capacity of biological oxidation plant than materials which are not completely oxidised in normal treatment conditions. But this is the kind of demand which sewage works are there to meet. And, in any case, having regard to the concentrations at which surface-active materials can normally be expected to be present in sewage, we consider that it would be a negligible factor compared with the order of reduction in effective purification capacity indicated by the evidence in paras. 89–93, above.

98. It must be noted further that for most sewage works one of the most important ultimate criteria for judging the efficiency of the treatment provided is the extent to which the oxygen content of the water in the river receiving the effluent remains at an adequate level. Whether or not a particular surface-active material significantly hampers the purification processes operating within the works, it may still reduce the efficiency of the works as measured by the yardstick mentioned if it passes through the treatment processes and into the river and there reduces the rate of aeration of the river water from the atmosphere. That some of the alkylarylsulphonates at present used in most household synthetic detergents do pass, in sewage effluents, into rivers has been shown in an earlier part of this Section. The question of the extent to which they may be affecting the aeration rate of the river water is discussed in Section V.

The effects of the "builders" on sewage treatment processes

99. We have devoted most of our attention to the surface-active materials on which synthetic detergents are based. It must not be forgotten that, though these constitute the most important part of household preparations, an even greater weight of auxiliary substances accompanies them. Whether or not these auxiliary substances are chemically changed during the washing process or during their passage through sewers, there will clearly be additional material arriving at sewage works. In the absence of specific experiments, we can make only a few general observations about this.

100. We have already said that, as a result of the widespread use of synthetic detergents, the phosphate concentration in sewage has probably increased by about 9 p.p.m. (expressed as P_2O_5). General experience with the normal phosphate content of sewage in the past was that about half was retained in sludge at sewage treatment works and the remainder discharged in the effluent. The phosphate content of sewages and effluents is but rarely determined, and we have as yet no information to show what the increased phosphate content in sewage actually is in practice, or whether in spite of the total increase the proportion removed during sewage treatment remains at about 50 per cent. Prima facie we would expect the phosphate content of sewage effluent now to be 4 or 5 p.p.m. greater than it was before the war. The possible effects of phosphates in rivers and water supply are explained later. In this section we need add no more than that there is no reason to suppose that their presence in sewage adds to the difficulties of sewage purification.

101. The effects of salts such as sodium sulphate and sodium chloride, in the amounts in which they occur in synthetic detergents, can be ignored so far as sewage treatment is concerned. We have no information about the effects of sodium carboxymethylcellulose, organic amides, or borates, which are present

in some household synthetic detergent products. In the relatively small quantities used, however, these materials do not seem likely to have any deleterious effect.

102. In general, then, the "builders" at present used in synthetic detergents do not appear to be of any significance to sewage treatment. It therefore seems necessary only to bear in mind their existence, and the fact (mentioned in para. 22) that their amount and nature may from time to time be varied, so that conclusions based on past experience of their use may need to be reviewed.

The non-domestic use of synthetic detergents not a general problem

103. We have made no reference so far to the question of the behaviour or effects, at sewage works, of the synthetic detergents used for industrial purposes. As explained in Section II, these constitute only a small proportion of the total amount, by weight, of the synthetic detergents nowadays used, and there is such a wide variety of them that the amount of any one type likely to be present in the average sewage will be negligible compared with the amount of domestic synthetic detergent present also. It may be that the ingredients of some of them could, in sufficient concentrations, give rise to difficulty at sewage works, but we have no evidence to suggest that in practice their use is causing sewerage authorities generally any problems. Moreover, they will usually be discharged to sewers in trade effluents, and over trade effluents sewerage authorities have a wide measure of control. For these reasons we have not regarded the industrial use of synthetic detergents as a matter needing our detailed examination, and in the sections of this report which follow we continue to deal primarily with the household washing products which form the bulk of the synthetic detergents sold.

V. EFFECTS OF THE USE OF SYNTHETIC DETERGENTS ON RIVERS AND STREAMS TO WHICH SEWAGE EFFLUENTS ARE DISCHARGED

Concentration of surface-active material in certain river waters

104. The work already described has shown that, of the anionic surface-active material in synthetic detergents at present entering sewage after use in household washing, as much as a half, or more, appears to resist the various treatment processes at sewage works and to be discharged in the sewage effluent—which means, in most cases, into rivers. The information so far available suggests that it is particularly material of the alkylarylsulphonate type at present used that persists in this way. The concentrations of surface-active material that will in consequence be found in the water of rivers below sewage works will vary widely, according to—among other things—the concentration of sewage effluent in the river, or stretches of river, concerned, and to the sewage effluent's surface-active content. Some of the material entering the river may be lost by adsorption or other processes during the passage of the water downstream. Probably in the lower reaches of any large river into which the only sewage effluent discharges are from small works well upstream—just as in the many rivers or stretches to which no sewage effluents are discharged anywhere—analysis would fail to show

any surface-active content at all. But there are many rivers in which, in certain stretches, the presence of surface-active material from synthetic detergents must now be expected in measurable concentrations—and this has already, in many cases, been established by analysis. Concentrations reported to us, mainly during a period when river flows in general have afforded a fair amount of dilution, have been as high as 0·2 p.p.m. in the Stour (Essex), 0·4 p.p.m. in the Ouse (Beds) and in the Thames at Teddington, 0·9 p.p.m. in the Warwickshire Avon, 1 p.p.m. in the Lower Lee, 1·5 p.p.m. in the tidal Thames, 2·5 p.p.m. in the Upper Lee, 3·0 to 3·5 p.p.m. in the Chelmer, Crouch, and Roding, and 4·9 p.p.m. in the Hertfordshire Colne. These figures are not necessarily representative throughout the year of all stretches of the rivers mentioned, nor were they all arrived at by equally reliable methods of determination. Nevertheless they provide an adequate confirmation of what must follow from the presence of surface-active materials in sewage effluents—that these materials are also present, though to a varying extent, in the water of some rivers. It thus becomes necessary to consider what effects these substances may have—not only in relation to any public drinking water supplies which may be drawn from downstream (discussed later in this report), but also on the condition of the river itself.

105. It should be noted in this connection that the surface-active material entering rivers in sewage effluents is not necessarily the same in all respects as the surface-active material in the synthetic detergents from which it is derived. It is the same *type* of material, but it may not have precisely the same properties; for example, there are some indications that it may have less toxicity to fish. It has not so far been found practicable to recover surface-active material from sewage effluent or river water in any large quantities, so some of the experiments mentioned later in this section have necessarily had to be carried out with material that has not passed through the processes of sewage treatment. The conclusions based on them must therefore be taken to indicate possibilities rather than certainties.

Foaming in rivers

106. In the last few years there have been Press reports about the periodic occurrence, on various rivers, of considerable amounts of foam, and the subject has aroused a certain popular interest. On one occasion during 1952, foam below Lemsford Mill on the River Lee covered an area of 1,500 square yards and built up to a height of 12 feet. We accordingly made enquiries of the River Boards' Association about the extent to which this condition was occurring over the country generally. Of their thirty-four members, fifteen Boards have reported foam to be occurring to an appreciable though varying degree on certain rivers within their areas; the other Boards either have no foaming, or have not been in a position to provide useful evidence about it. The rivers said to be affected include the Bristol Avon, the Dee in Cheshire, the Lee in Hertfordshire, the Nene in Northamptonshire, the Arun and Adur in Sussex, the Aire, Calder, Rother, Don and their tributaries in Yorkshire, and the Thames, the Trent and the Severn and a number of their tributaries. Though there is little evidence available of a direct nature, the foaming is mostly attributed by the River Boards to the presence in the water of synthetic detergents or their residues. It is frequent in occurrence, but the area affected and the persistence of the foam varies considerably with local weather or other conditions. As would be expected, it seems to be most pronounced on those rivers that afford the least dilution to the

effluents discharged into them. Where ample dilution exists, foaming is generally restricted to a few yards from a turbulent discharge.

107. In general, the foaming is most pronounced, and is often recurrent, below weirs and at similar places where the surface of the water is broken up. The nature of the weir itself appears to be material, for shallow weirs and those with comparatively long aprons of low angle are not so conducive to foam formation as the others. If there is any wind, its direction exerts a marked influence, for an upstream wind causes foam below weirs to bank up into compact masses, whereas a downstream wind assists in the foam's dispersal and disintegration.

108. It may be noted that certain streams in Lincolnshire receive appreciable amounts of sewage effluent, presumably containing synthetic detergent residues, but appear to suffer no appreciable amount of foam. This may well be due to the sluggish nature of their flow.

109. Certain spectacular instances of foaming have clearly coincided with increased sales of synthetic detergents in the districts concerned. One such instance occurred in a part of the Bristol Avon in which there had been no appreciable trouble of this kind previously. On 28th October, 1953, and continuing for about three weeks, unusual foaming occurred—to an extent that has not since been common on this river—below every weir over a 30-mile stretch. It was found that a sales promotion campaign had begun on 26th October, 1953, with free distribution of a packet of a new brand of synthetic detergent to every household in the area concerned. Similar if less striking instances have been reported elsewhere.

110. There can be no doubt that persistent foam makes a river look less pleasant —or more unpleasant—than it would look otherwise, and although the foam itself is usually white there are indications that it can darken riverside foliage and may eventually kill it. Moreover there have been complaints by property owners and road-users of nuisance and damage from foam blown off rivers by the wind.

111. So far, few attempts have been made in this country to control foaming on rivers by measures taken on the rivers themselves. Any method adopted for this purpose would clearly need to be formulated specifically to meet the individual circumstances. The physical factors (e.g. weirs) conducive to foaming could seldom, in practice, be either eliminated or conveniently adapted so that the foam collapses or is sucked down. Adoption on rivers of any of the means discussed in Section IV for suppressing foam at sewage works would generally be impracticable—and the use of defoamants, in particular, would be open to the serious objection that it would involve, in effect, polluting the river water. In any event the mere suppression of foam on a river, without removing the original cause of its occurrence, might in the long run be a mistake. The presence of foam may well be a convenient, cheap and reliable indicator of undesirable conditions in the river water (these are dealt with below), so that on all grounds it would be better to prevent the conditions than merely disguise the symptom.

Effect of synthetic detergents on concentration of dissolved oxygen in river water

The importance of the dissolved oxygen concentration

112. As explained earlier in this report, the effluent from a sewage works still contains some substances that will undergo oxidation when the effluent is

discharged to a surface water. The test for biochemical oxygen demand is a measure of the quantity of this residual oxidisable material. At the biological stage of treatment in a sewage works the oxygen required for oxidation is supplied at a high rate. In a river or estuary the rate at which oxygen can be supplied to the bulk of the liquid is much lower. Its chief source (neglecting the photosynthetic activity of plants) is the air. Clean water that has been exposed to the air for some time, until it is saturated with oxygen under those conditions, contains in solution about ten parts per million of oxygen, the exact amount depending on the temperature, and in estuaries on the salinity, of the water. If a sewage effluent is added to this water, the polluting constituents in the effluent begin to be oxidised, chiefly as a result of the action of bacteria, and in this process part of the oxygen in solution in the water is used up. A further quantity of oxygen is then dissolved from the air by the water, the rate of solution increasing as the concentration in the water is reduced. Thus the two opposed processes—consumption of the water's dissolved oxygen by the polluting matter and renewal by solution from the air—are occurring at the same time, and under conditions of equilibrium the level of oxygen in solution adjusts itself until the two processes go on at an equal rate. The greater the rate of oxidation of the polluting matter or the slower the rate of solution from the air the lower will be the equilibrium concentration reached.

113. One of the chief considerations in regulating the discharge of polluting matter to surface waters is that the oxygen level in the receiving river or estuary should not fall below a certain limit. There are several reasons why this is of importance. One is that fish will not live in water containing less than a minimum quantity of dissolved oxygen; moreover the toxic effect on fish of many constituents of sewage effluents and industrial effluents is greatly increased by reduction of the oxygen content of the water in which they are present. Another and very important reason is that if the rate at which oxygen is being withdrawn from solution by bacterial activity exceeds the maximum rate at which it can be dissolved from the air, and the concentration of oxygen in solution in consequence falls to zero, a marked change takes place in the general condition of the water and in the processes occurring in it. At this point organic constituents, whether dissolved in the water or deposited on the bottom, begin to undergo anaerobic decomposition, with the liberation of foul-smelling gases and volatile substances, so that a public nuisance may be caused. An example of this condition is at present afforded by the tidal Thames, to the middle reaches of which are discharged large volumes of sewage effluent, and other wastes, from London. In dry weather the rate at which oxygen is absorbed by these discharges nowadays exceeds the maximum rate at which it can be dissolved by the water from the air, and over a distance of some 10 to 20 miles the water contains no detectable quantity of oxygen in solution. Under these conditions hydrogen sulphide—a foul-smelling and corrosive gas—is evolved. So obnoxious has this condition become that all possible remedies are being canvassed—and the sewerage authorities concerned have found it necessary to put in hand extensive improvement schemes to increase the extent of purification given at the principal treatment works, at a total capital cost of many millions of pounds. It is clear, therefore, that anything reducing the rate at which oxygen is dissolved from the air by the water of the estuary is of great importance. In a largely closed system such as the tidal Thames, if the rate under given conditions were reduced by, say, 20 per cent, the level of concentration of oxygen in the water would fall,

and it would return to its original value only if the quantity of oxidisable matter discharged to the estuary were similarly reduced by nearly 20 per cent. The cost of making such a reduction would obviously be very great.

The reduction of the dissolved oxygen concentration by surface-active materials

114. There had been reports for some time, based on laboratory experiments, that one effect of the anionic surface-active agents at present in common use is to reduce the rate at which oxygen is dissolved by water under given conditions. This was shown for certain types of surface-active substances by work done in England in 1952, and work in America has shown it also for a number of proprietary household synthetic detergent mixtures. The Water Pollution Research Laboratory of the Department of Scientific and Industrial Research, which for some years has been making a survey of the tidal Thames, recently found (while studying the many factors having a possible bearing on the river's present state) that anionic surface-active agents are now usually present in the estuary water, the maximum concentration, which usually occurs near the position of the two main sewage works outfalls at Barking and Crossness, being reported as about 1·5 parts per million. For some time, therefore, the Laboratory has been carrying out experiments in an attempt to estimate what the effect of the synthetic detergent substances would be on the rate of solution of oxygen in the Thames estuary, and in fresh-water streams, under different conditions. Experiments were carried out in the laboratory with samples of distilled water, tap water, and sea water, and later with tap water in a 4,500-gallon wave tank; their re-aeration rates after being deoxygenated were studied under varying conditions, including the addition of known quantities of the common packaged synthetic detergents. Similar experiments were carried out using only the surface-active materials on which these synthetic detergents are based. Then comparisons were made of the re-aeration rates of effluent from the biological treatment of sewage from which synthetic detergents had been excluded as far as possible, and of effluent from sewage to which, before treatment, known quantities of synthetic detergent had been added. Finally a large-scale experiment was carried out with natural stream water; an unpolluted lakeland stream with a dry weather flow aproaching a million gallons daily was deliberately deoxygenated, and then its re-aeration rates with and without a content of surface-active material were compared. The results appeared to confirm the conclusions reached from the earlier and smaller-scale work mentioned above, that the surface-active materials reduce the rate of solution of oxygen by water. The degree of reduction appears to depend partly on the cleanliness of the water, and also on the extent to which it is agitated—there being little or no effect when the water is agitated either intensely or not at all, and a marked reduction in the region between these two extremes.

115. Further work of this kind will need to be done before a full picture emerges of the exact nature and importance of the role that synthetic detergents play. Certainly they are not by any means the only or the biggest factor affecting the condition of river waters. But it seems clear from what has already been done that there will be certain rivers in which the presence of surface-active materials derived from synthetic detergents will reduce re-aeration and will thus cause, other things being equal, a lowering of the concentration of dissolved oxygen in the water—which is a tendency in the wrong direction.

Effects of surface-active materials on river plants and animals

116. So far, little has been reported—or is known—about the effect of anionic surface-active materials on water plants. On the one hand it has been stated that the material derived from foam floating on sewage effluent produces discoloration of the leaves of the fresh-water plant *Potamogeton densus* within 14 days when present at a concentration equivalent to approximately 6 p.p.m. of surface-active material, and that a concentration of about 9 p.p.m. produces the same effect in one day. On the other hand some workers examining a number of water plants have not observed any effect from several types of synthetic detergent in concentrations of about 40 p.p.m.

117. More is known about the effects of surface-active agents on fish. In laboratory experiments by various workers, stickleback, minnow, and rainbow trout respectively were kept for varying periods in water in which known quantities of surface-active material (mainly alkylarylsulphonates) were present. The toxicity of the material to the stickleback appeared to be low; the toxicity to the minnow appeared to be of the same order as that found for rainbow trout—which are usually more susceptible to adverse conditions than are most coarse fish. Of the trout, some died during a period of 12 days in water containing about 5 p.p.m. of active material (mainly alkylarylsulphonate) and some during periods of 12 weeks in water containing about 3 p.p.m. These concentrations are of the same order as have been reported in some sewage effluents, though they are considerably higher than could normally be expected in most of the rivers to which such effluents are discharged.

118. As noted in para. 105, it appears that given concentrations of surface-active material may be less toxic to fish where the material has passed through biological treatment plant at sewage works than where it is added direct to the water as in the laboratory. On the information at present available it seems unlikely that fish are being or would be killed in rivers in this country by the toxic action of surface-active agents alone. On the other hand, laboratory studies have shown that at least some types of surface-active material can increase the susceptibility of fish to low concentrations of dissolved oxygen (which usually occur in polluted rivers), and also that a comparatively small reduction in the oxygen content reduces the period of survival of trout in water where surface-active material is present at a toxic concentration. Moreover, the action of different poisons is often additive.

119. Probably, therefore, the presence of surface-active agents in rivers, if it has a detectable effect on fish, is less likely to show itself by causing extensive mortality from time to time than by acting in conjunction with other adverse factors and so extending those parts of a polluted river in which fish cannot live continuously. Work is in progress to ascertain the extent to which this may occur. Meanwhile, although anglers have from time to time expressed fears about the effects of synthetic detergents on fisheries, there is, so far, no authenticated evidence of direct damage. In fact in one instance it is known that good catches have been reported in the last two seasons in a river subject to heavy foam, whereas a few years ago (when the principal sewage effluent discharged into the stream was of poorer quality) there were no fish.

Effects on rivers of the phosphates in synthetic detergents

120. We have so far dealt only with the implications of the discharge to rivers, in sewage effluents, of some of the surface-active materials. As mentioned earlier,

however, some of the "builders" in synthetic detergents are likely to get into rivers also—notably the phosphates. Sewage effluents, particularly in the United States, appear to have been showing a marked increase in phosphate content since synthetic detergents of the now common kind came into widespread use. In the United States there has been some concern about consequent excessive weed growth—or the possibility of it—particularly where the rivers concerned are used for water supply. There is no evidence yet of any general trouble of this kind on rivers in Great Britain.

Effect on rivers of the discharge of sewage effluents of reduced quality

121. In para. 96 we expressed the view that the presence in sewage of alkylaryl-sulphonates of the kind now being used in synthetic detergents probably lowers the efficiency of the purification processes at sewage works and hence the general quality of the effluents discharged. The adverse effects of any such worsening of general effluent quality on the condition of the receiving rivers would be additional, and in some ways complementary, to any adverse effects exerted on the rivers (see paras. 114–119 above) by the presence, in the sewage effluents discharged to them, of residual surface-active materials of the type mentioned.

VI. SYNTHETIC DETERGENTS AND WATER SUPPLIES

Effect on river-drawn water supplies of reduced purification at sewage works upstream

122. A large number of statutory water undertakings, supplying in total about a quarter of the population, derive their water from rivers that receive effluents from sewage treatment works upstream of the water supply intakes. The communities supplied in this way include London, Norwich, York, Newcastle, Coventry, Gloucester, Worcester, Oxford, Southampton, Chelmsford and Southend. To the extent that, for reasons mentioned in an earlier section, the general quality of those effluents and hence of the river water is liable to be worsened by the effects of synthetic detergents on sewage purification processes, the water undertakers downstream will be drawing a more polluted water than they would otherwise do. Consequently unless additional purification is provided at the waterworks the supplies given to consumers may be of reduced chemical and bacteriological quality. It is unlikely, however, that any water undertakers will in practice be in a position confidently to ascribe a general deterioration in the quality of their raw water supply to this cause, since variations in the efficiency of sewage purification works can arise for a number of reasons. The amount of surface-active material they might find present in the intake water, though of importance for other reasons (see below) would not in itself give any clue to this. Accordingly, if raw water supplies at any river waterworks appeared to be worsened in general quality, and if this worsening were linked with a deterioration in the quality of sewage effluents discharged upstream, it would be for the sewerage authority concerned, not the water undertakers, to show whether the trouble arose primarily from the growing use of synthetic detergents or from some other cause or combination of causes. Conclusive evidence on this would not be easily obtained; in Section IV, however, we have mentioned a number of indications that appear to us to be of significance.

Concentration of surface-active material at waterworks intakes

123. Irrespective of whether its general quality is appreciably worsened by reduced efficiency of sewage treatment upstream, the water of the rivers concerned is nowadays fairly certain, as explained in the two preceding sections, to contain residual ingredients of synthetic detergents—in particular, of the surface-active materials on which these products are based. The concentrations at which these materials are still present in river water by the time it reaches waterworks intakes must differ from place to place, according to variations in synthetic detergent usage, in water consumption, and in sewerage and sewage disposal arrangements, amongst the communities upstream, and also to differences in the characteristics of the rivers. One major cause of variation will be changes from one stretch of river to another, and from one time to another, in the amount of natural dilution. It may be expected, for example, that other things being equal the concentrations of surface-active material in most rivers where it is present will be much higher after a dry winter and summer than in 1953 and 1954. It is also quite possible that some of the surface-active materials discharged in sewage effluents are arrested, oxidised or otherwise inactivated by natural processes in the river before reaching water supply intakes. But a proportion of them persist well downstream.

124. Until recently the concentrations of surface-active material thus still present in river water at waterworks intakes were seldom measured in this country. Lately, since attention began to be focused on these materials, and with the development of various procedures for measuring their amounts, more and more River Boards and water undertakings are beginning to make determinations of this kind fairly regularly. We thus possess some evidence from waterworks intakes to support what we would expect from knowledge of river flows and evidence available at sewage works outlets. The attached table shows, for example, the monthly and annual average concentrations of surface-active material reported from the main intakes of the Metropolitan Water Board for 1954, which was generally a wet year with high river flows. The averages for the Board's River Thames intakes were based on figures varying between 0·03 and 0·5 p.p.m. There was no observable increase compared with 1953. The variation at the Board's New Gauge intake on the Lee was between 0·2 and 0·9 p.p.m. There was some slight evidence of an increase since the previous year. The figures for the Board's Lee intake at Chingford Mill varied between 0·2 and 1·0 p.p.m.—again showing a slight increase over 1953.

125. These reports relating to the intakes used for water supply to London were paralleled by reports we received of concentrations of surface-active material measured in October 1953 and October 1954 at the intakes used by certain water undertakers in Essex; the figures varied between less than 0·2 and 0·5 p.p.m.

126. We have since obtained information from certain other water undertakers about the concentrations measured at their intakes (using the revised method of determination we have recommended) at various periods during the early part of 1955. A spot sample of the water abstracted by the Coventry undertaking at their intake on the Severn showed a concentration of 0·3 p.p.m.; samples taken daily over a fortnight at their intake on the Avon (not now in use) gave results ranging between 0·5 and 1·1 p.p.m. The Bedford intake on the Ouse showed concentrations ranging between 0·1 p.p.m. and 0·3 p.p.m. over a fortnight in

Concentration of surface-active material at the river water intakes of the Metropolitan Water Board in 1954 (see para. 124)

Monthly and annual averages in parts per million

	January	February	March	April	May	June	July	August	September	October	November	December	Average 1954
River Thames, Laleham Intake ..	0·24	0·18	0·19	0·18	0·24	0·19	0·29	0·32	0·35	0·35	0·24	0·14	0·24
River Thames, Walton Intake ..	—	0·19	0·16	0·24	0·24	0·24	0·27	0·30	0·24	0·27	0·30	0·13	0·23
River Lee, New Gauge Intake ..	0·43	0·59	0·51	0·48	0·54	0·43	0·67	0·54	0·54	0·66	0·51	0·48	0·53
River Lee, Chingford Mill Intake	0·42	0·37	0·30	0·34	0·43	0·46	0·54	0·53	0·43	0·82	0·45	0·27	0·45

NOTE: The determinations on which this table is based were made by a method believed to be less accurate than the revised method described in Appendix A, which was not devised until late in 1954. The results were, however, adjusted so as to be as far as possible comparable with what could bave been expected to have been obtained by the revised method, and are here expressed by reference to the same standard material.

March; monthly determinations made between March and September gave results ranging between 0·2 and 0·4 p.p.m. The South Essex Waterworks Company reported concentrations at their Stour intake of about 0·1 p.p.m.; a spot sample from their Layer Brook source had a concentration of 0·6 p.p.m.

127. As explained earlier, these figures individually may not all be free from error. But taken together, along with information which has been supplied by certain River Boards and other bodies, and with the considerable amount of evidence available as to the content of surface-active material in the sewage effluents which rivers receive, they confirm that water abstracted for public supply from rivers below sewage works outlets can generally be expected to contain measurable quantities of surface-active material, though the concentrations may be expected to vary from one time and place to another.

Concentration of phosphate at waterworks intakes

128. As mentioned in an earlier section, the growing use of household synthetic detergents is likely to lead also to an increased phosphate content in river water below sewage works, and hence in the water at some waterworks intakes. Such an increase has been observed by the Metropolitan Water Board. The average concentrations of phosphate (expressed at PO_4*) at the Board's River Lee (Chingford) and River Thames (Walton) intakes between 1939 and 1952 remained fairly constant at, respectively, 0·40 and 0·45 of a part per million. In 1953 the corresponding figures were 0·81 and 0·78 p.p.m., and in 1954, 1·02 and 0·69 p.p.m. Figures for the New Gauge intake from the River Lee at Hertford (where in dry weather up to half, or more, of the river's flow may consist of sewage effluent) were not available before 1953; in that year, however, the phosphate concentration was 1·69 p.p.m., and in 1954 it was 1·61 p.p.m. It seems a reasonable assumption that some, at least, of these relatively high present-day concentrations are due to the increased use of synthetic detergents, and that concentrations materially greater than formerly will also be present, for the same reason, at other waterworks intakes where the river contains sewage effluent.

The effects of the surface-active materials, and of the increased phosphate content, on the water's treatment

129. Experiments have shown that a mixture of proprietary synthetic detergents in water, at as low a concentration as 0·8 p.p.m. of active material, can cause persistent foam. We have not heard of any such foam in public water supplies as delivered to consumers in this country, but it will be noted from what is said above that the concentration of surface-active material at which foam can occur has already been reported at some waterworks intakes, and foaming has been observed on certain rivers above such intakes, and even in one waterworks.

130. Besides being able to cause foam, synthetic detergents are excellent wetting, emulsifying, dispersing and deflocculating agents; they have the ability at certain concentrations to maintain substances in a state of suspension in water; and in general they are chemically stable, retaining these properties even in high dilution and over a wide range of pH. The purification of water involves the removal from the water, by flocculation, precipitation, etc., of as much material as possible.

* This is the usual way of expressing phosphates in chemical analysis of water. In earlier sections dealing with synthetic detergent manufacture, and with sewage treatment, phosphate concentration has been expressed in terms of P_2O_5 (see footnote on page 8).

It is evident, therefore, that the fundamental aims of detergency are directly opposed to water treatment. At present the concentrations of synthetic detergent ingredients in the river intakes of waterworks in this country are apparently not of an order large enough for these opposing tendencies to conflict in any noticeable way. But certain experimental work in the United States has suggested that in the alum coagulation process of water purification the presence of phosphates derived from synthetic detergents can cause difficulty at concentrations of about 1 p.p.m., so the possibility of interference with treatment cannot be ruled out. Moreover, an increased phosphate content in the raw water supply is also liable to lead to more prolific algal growth; this too could embarrass water treatment processes, particularly filtration, and there would be a greater likelihood of unwanted tastes.

131. We have enquired whether there is any risk of unwanted taste being imparted to water by the synthetic detergent residues themselves—particularly the surface-active materials. It is known that a "soapy" taste can be detected in water containing synthetic detergent mixtures. But this is only at concentrations of 4·0 p.p.m. of surface-active material or higher; concentrations as high as this have not, so far as we are aware, been present in any tap-water supplies received from public water undertakers in the United Kingdom. Probably before they could occur there would be ample warning, from foaming and perhaps other phenomena, during the water's treatment.

132. Indeed, so far as observed effects are concerned there is no evidence that the presence of synthetic detergent residues in raw water supplies has yet affected the purification processes at any waterworks in this country. In 1953 there were two cases of trouble at waterworks in the United States associated with the presence of synthetic detergents after exceptionally low river flow. At each of the two works considerable foaming occurred in the intakes and on sections of the plant; the coagulation and settlement processes were hampered; and the filtered water passing into supply was discoloured, with a fishy taste and smell. The concentration of surface-active material present in the raw water during most of the period of difficulty appears to have been between 1 and 2 p.p.m., and only a very small proportion was removed during purification. But the conditions obtaining at the time appear to have been unusual, and we have heard of no comparable trouble elsewhere.

Persistence of surface-active materials through normal waterworks processes

Experimental work

133. Experiments have been carried out with Thames-derived water, an alkaline hard water usually coming in the category of that from a "fairly clean river" and with an average content of surface-active material (before dosing) reported as 0·24 p.p.m. In these experiments the water was dosed with synthetic detergents based on surface-active materials of the type shown by experience not to be completely removed by sewage treatment, and hence likely to be present in river water. The doses, though not excessive, were of an order to give rise to nuisance from foaming. The amount of surface-active material in the water before and after each particular treatment was measured at regular intervals. The results of the experiments, and the conclusions drawn from them, are summarised below.

(a) *Storage of river water* in a reservoir for three weeks reduced the concentration of surface-active material by 20 to 50 per cent, depending upon prevailing temperature conditions, but further removal was slow, and subsequent experiments showed that from 20 to 45 per cent of the active material originally added might still be present after six months' storage. This suggests that even under ideal conditions one could not necessarily expect more than a 50 per cent removal within a reasonable period of storage.

(b) *Slow sand filtration* (passage of the water through fine sand at the slow rate of 4½ inches per hour) again brought about a reduction of the concentration of surface-active material, the amount of reduction depending upon the prevailing temperature and varying between 13 and 50 per cent. Thus, assuming that the material remaining after prolonged storage would be capable of further reduction by other means, it seems that the combination of long storage and slow sand filtration during the summer might bring about a 75 per cent reduction in the original surface-active agent content, but in winter conditions the total reduction achieved by the two methods in combination might be as low as 30 per cent.

(c) *Coagulation and rapid filtration* were reported, in two separate experiments in the United States, to reduce the surface-active concentration in the water treated by, respectively, 7·5 per cent and 20 per cent. Preliminary jar tests in this country, however, using aluminium sulphate as the flocculating agent, suggested that this process had no effect at all on the content of surface-active material. Treatment of a hard river-derived water with aluminium sulphate and activated silica on a plant scale (300,000 gallons daily), and then by rapid filtration, had only a slight effect—certainly not bringing about a reduction of more than 10 per cent.

(d) *Experiments with activated carbon* showed that it was effective in removing surface-active material from water. For example, 40 p.p.m. would remove about 30 per cent, and 100 p.p.m. would remove about 75 per cent, from a solution originally containing about 6·5 p.p.m. of active material. It should be noted, however, that the use of activated carbon at these concentrations would be neither practicable nor economic for the continuous treatment of water on any large scale.

(e) *The chlorination process*, although its sterilising efficiency is not affected by the presence of surface-active material in concentrations of 6·5 p.p.m., does not remove these materials when applied at the levels normally used in water treatment.

Observations at waterworks

134. Frequent estimates were made of the concentration of surface-active material in the water passing through the stages of purification at various works of the Metropolitan Water Board during 1954, and they are summarised in the table on page 42.

135. It will be seen that there was relatively little surface-active material in the River Thames at the Laleham and Walton intakes, and no removal of it during passage through the reservoirs, but considerable removal during filtration. These results, in so far as they relate to storage, differ from the experimental findings. As regards the River Lee results it should be noted that the water

Samples taken during 1954 *from*	*Average concentration of surface-active material in p.p.m.*
River Thames at Laleham ..	0·24
Queen Mary reservoir	0·26
Kempton Park filtered water ..	0·11
River Thames at Walton	0·23
Knight & Bessborough reservoir	0·30
Walton filtered water	0·12
River Lee at New Gauge ..	0·53
Hornsey works filtered water ..	0·15
River Lee at Chingford Mill ..	0·45
Lee Bridge Aqueduct	0·36
Lee Bridge filtered water	0·18

abstracted at New Gauge receives no storage; in order to treat it satisfactorily it is usually diluted with half its volume of high quality well water, and it is this dilution that probably accounts for most of the reduction shown. Any further reduction in surface-active content observed here seems to be due to slow sand filtration. The River Lee water abstracted at Chingford Mill is stored, and the results for the water in the Lee Bridge Aqueduct indicate some reduction in surface-active content after storage, possibly owing to the absolute content of surface-active material being greater than in the Thames, and to the high bacterial activity in Lee water due to the presence of a higher proportion of sewage effluent. Again a good reduction seems to have been achieved by the subsequent process of slow sand filtration.

136. Throughout the second half of 1954 weekly determinations were made by the Southend Water Company at their Langford works where river water (mainly from the Chelmer) is stored for a week before treatment. The degree of removal of surface-active material in the works seldom appeared to be as high as 50 per cent and was usually reported as very considerably less. A series of determinations made by the South Essex Waterworks Company every few days between May 1954 and February 1955 of the concentrations of surface-active material in their River Stour intake and in their Abberton Reservoir, where up to a year's storage is given, appeared to show an average reduction of surface-active concentration during storage of about 50 per cent. Two sets of sample analyses at these works early in 1955 using the revised method we have recommended suggested that a further 30 per cent was removed by double sand filtration. At the Bedford Waterworks on the Great Ouse, where virtually no storage is provided, determinations over three weeks in early 1955 using the revised method suggested that the proportion of surface-active material removed from the raw water during treatment was on average 45 per cent—slow sand filtration effecting slightly better removal than alum treated pressure filters. During the summer months at these works the average degree of removal dropped to about 33 per cent. Two sample analyses by the revised method at the Coventry Waterworks on the River Severn in April 1955 indicated a 33 per cent reduction in surface-active concentration at these works also.

Conclusions on the effects of synthetic detergents at waterworks

137. It appears that appreciable concentrations of surface-active material may

be reached at some waterworks intakes, and yet the water purification processes available do not appear to remove it all; some processes at times remove very little. It is important that water undertakers should note the precise extent to which their supply is thus affected, and this illustrates the desirability of their using a reliable method of determination. The surface-active material is likely to be accompanied by an increased content of phosphate. The possibility cannot be ruled out not only that foaming could sometimes occur in the waterworks concerned, but also that in certain of them—particularly those equipped only with coagulation and rapid filtration plant—there might be a reduction of quality, and even foaming, in the finished supply. So far no such trouble has been reported in this country, but two cases have been reported from abroad—though they seem to have arisen in unusual circumstances.

138. Moreover, in areas where the public water supply is derived from rivers to which sewage effluents are discharged upstream, the drinking water drawn by consumers from the tap must already have begun to contain slight traces of surface-active materials. The question arises whether their presence in the water is harmful to the consumer. Evidence of ill-effect would have become available already if any short-term risk existed, since many millions of people in this country must have been drinking such water for some years. We know of no evidence whatever to suggest that any short-term ill-effect has in fact occurred. The possible effect of repeated ingestion of even minute amounts over a prolonged period is a different matter; we cannot argue merely from the lack of evidence in the last few years. It is clearly desirable that the matter should be kept under review.

139. The difficulties or queries that may thus arise for a number of water undertakings, as a result of the growing use of synthetic detergents of the present type, are not equally important in all cases. In some undertakings even a small further increase in the use of synthetic detergents by communities upstream could be cause for concern; other water undertakings may for geographical or other reasons have a larger margin of safety. Similarly the concentrations of surface-active material present in the tap water supplied by the affected undertakings must vary considerably from one district to another.

VII. IMPLICATIONS OF THE PERSISTENCE OF INGREDIENTS OF SYNTHETIC DETERGENTS IN SEWAGE WORKS AND IN THE WATERS TO WHICH SEWAGE EFFLUENTS ARE DISCHARGED

Features in the evidence which give rise to concern

140. To those concerned with the operation of sewage treatment works, the condition of rivers, and the purity of public water supplies, the following features of the evidence we have considered must cause some anxiety:—

(*a*) The use of synthetic detergents is substantial, and widespread. The bulk of them are household preparations based on anionic surface-active materials accompanied by substantial quantities of phosphates. Generally these surface-active materials and phosphates are after use discharged to sewers and thence to sewage treatment works.

(*b*) At the sewage treatment works, the surface-active materials and phosphates at present mainly used are not being completely removed or destroyed during sedimentation and biological oxidation. Their presence during treatment is accompanied by foaming, which is a nuisance and sometimes a danger, at virtually all activated sludge works and to a less extent at certain other works. It should usually prove possible to suppress this foam (so far as its occurrence on the works itself is concerned) with varying degrees of effectiveness, difficulty, and expense, although no one method seems suitable for general application.

(*c*) Whether foam occurs at sewage works (or is suppressed) or not, the surface-active materials with which it is associated are considered on balance to have some adverse effect on the sewage treatment processes and hence on the general quality of sewage effluents discharged to rivers. Further, these effluents now contain significant quantities of surface-active material, and an increased phosphate content.

(*d*) In consequence the water in some stretches of river in this country now contains surface-active material, and probably more phosphates than formerly. The surface-active material, in concentrations of the order which could be present at times in some rivers, can cause foaming, and may in certain conditions act so as to reduce the rate of oxygenation of the water, and this in some cases could contribute to an acceleration of the onset of offensive or (as regards fish) toxic conditions. The phosphates in excessive concentrations could stimulate undesirable growths. To the extent that any river water is thus worsened in general quality by reduced sewage treatment efficiency, or a reduction in re-aeration capacity, or an increased phosphate content, or by some or all of these factors acting together, riparian amenities and fish life are likely to be affected adversely.

(*e*) Certain rivers downstream of sewage works are used as sources of drinking water for a quarter of the population. In the purification of this supply, account must be taken not only of any lowering of the water's general quality by the above-mentioned factors, but also of the fact that some surface-active materials and phosphates are apparently still present in it where it is abstracted. It seems possible that in extreme conditions these substances may interfere with water treatment and cause foaming. Even in normal conditions the surface-active materials do not appear to be completely removed during treatment or storage and must therefore be present in small quantities in all the water supplied to consumers by the undertakers concerned.

Grounds on which the need for concern might be queried

141. It will be noted, however, that much of this evidence consists only of indications and possibilities—sometimes qualified ones—and that any difficulties or risks referred to would not necessarily arise to an equal extent, if at all, in all parts of the country. It must be borne in mind, further, that synthetic detergents have now been widely used for some years and yet there has been

little evidence so far of serious trouble being caused to sewerage authorities, water undertakers or the public generally, except for excessive foaming on a number of sewage works and rivers. Some water undertakers and sewerage authorities have had problems, but they do not appear to have been insuperable. Moreover, there is a sizeable though diminishing number of sewage works where any difficulties experienced in operation must be largely due to enforced deferment of modernisation and extension schemes necessitated by normal growth of the load on the plant. Finally, looking to the future, there is the consideration that though a continued increase iu the consumption of household synthetic detergents may be expected we are advised that it is unlikely to be nearly as rapid as that which has occurred in the last few years.

Discussion

142. The synthetic detergents to which we have been mainly referring are based on materials derived from petroleum products, and so result in a substantial saving in the cost of imported vegetable oils and fats; they earn valuable amounts in export markets; are highly efficient and popular; and meet a wide variety of needs, particularly in hard water areas where their use gives consumers special benefits. Taken as a whole, are the various difficulties or possibilities mentioned above, to which their disposal after use gives rise, sufficient to justify concern? We believe they are (though in the case of four of our number this is subject to certain reservations explained at the end of the report). Our reasons are given below.

The increasing need for safeguarding the public health services

143. This country has a higher population, a greater water consumption, a more extensive system of sewerage, and a larger and more complex flow of industrial production and therefore of industrial wastes, than ever before in its history. More sewage effluents of domestic and industrial origin go into our inland rivers than ever before; and more inland river water than ever before is used for humau consumption. Yet today the population is free, and expects to remain free, from the offensive conditions and the widespread outbreaks of waterborne disease that were a feature of life in this country until after the end of the last century. This freedom from conditions associated with poor sanitation and indifferent water supplies has been achieved in spite of the fact that the density of our population is greater than in most other countries, and our natural watercourses are smaller. Among the major causes of improvement have undoubtedly been the measures taken during the last hundred years, and continually strengthened, towards the provision and the maintenance of adequate sewerage, of safe sewage disposal, and of a pure supply of piped water, in all but the very smallest communitics.

144. The present position, however, has been attained only by considerable expense and effort and constant vigilauce. The need for such vigilance is today greater than ever, to protect what has been achieved and to prevent the cost and difficulty of further progress from become prohibitive. Water consumption and sewerage provision are still increasing rapidly; this results in continually increasing discharges of sewage effluent into rivers, and thus in an increased proportion of sewage effluent in river waters, and in the water available for supply after treatment to many of our great towns aud their surrounding areas. On a number of rivers, including some used for water supply downstream, this

trend is being accelerated by growing use, for water supply, of the rivers' head-waters and underground sources, with a consequent diminution in the amount of dilution available lower down. Current projects for industrial and town expansion, and the progress being made in the extension of piped water and main drainage in rural areas, are bound to accelerate the trend still further. At the same time the community in general has become increasingly dependent on the efficiency and expandibility of its water supply and sewerage services for the maintenance of its pattern of life and livelihood. For these reasons, inland sewerage authorities in general are being compelled to shoulder ever-increasing tasks and responsibilities in the purification of sewage; water undertakers dependent on rivers below sewage works outlets are having to face continually growing problems in ensuring the maintenance of adequate, pure and wholesome supplies.

145. But there is a limit, in practice, to what can be done by way of purification, whether at sewage disposal works or at works for the treatment of river water. No practicable means of sewage treatment can ensure the discharge of effluent consisting of water entirely free from sewage-derived contaminants. No practicable waterworks treatment can ensure that, where such contaminants are present in the raw water, they can be entirely removed before the water is put into supply. The best we can expect is that the amount and nature of the contaminants remaining in sewage effluents discharged to rivers shall be kept within the limits shown by experience to be prudent. The observance of such limits by sewerage authorities, however, requires, among other things, that no greater or more complex burden should be placed on the sewage works than can be adequately disposed of with the plant which is available or which could reasonably be expected to be provided.

146. It was clearly with considerations of this kind in mind that Parliament enacted, in Section 27 of the Public Health Act, 1936, that:—

> "No person shall throw, empty or turn, or suffer or permit to be thrown or emptied or to pass, into any public sewer, or into any drain or sewer communicating with a public sewer—
>
> (a) any matter likely to injure the sewer or drain, or to interfere with the free flow of its contents, *or to affect prejudicially the treatment and disposal of its contents*; or
>
> (b) any chemical refuse or waste steam, or any liquid of a temperature higher than one hundred and ten degrees Fahrenheit, being refuse or steam which, or a liquid which when so heated, is either alone or in combination with the contents of the sewer or drain, dangerous, or the cause of nuisance, or prejudicial to health; or
>
> (c) any petroleum spirit, or carbide of calcium."

and that the same Act stipulated (Section 30) that:—

> "Nothing in this Part of this Act shall authorise a local authority to construct or use any public or other sewer, or any drain or outfall, for the purpose of conveying foul water into any natural or artificial stream, watercourse, canal, pond or lake, until the water has been so treated as not to affect prejudicially the purity and quality of the water in the stream, watercourse, canal, pond or lake."

and (Section 31) that:—

"A local authority shall so discharge their functions under the foregoing provisions of this Part of this Act as not to create a nuisance."

147. Legislation in the following year went further. The wastes that were then causing most serious concern because of their possible effects when discharged direct to rivers, and yet could do severe damage at sewage works if discharged indiscriminately to public sewers, were those from trade premises. So the Public Health (Drainage of Trade Premises) Act, 1937, provided a code under which trade wastes might be admitted to public sewers, but with safeguarding provisions giving the sewage treatment authorities wide powers of control over the amount and nature of what could thus be discharged. The Water Act, 1945, contained various provisions designed to protect the sources used by water undertakings from pollution, but did not deal extensively with discharges to rivers as such. The River Boards Act, 1948, however, and the Rivers (Prevention of Pollution) Act, 1951, together with the corresponding Scottish legislation, completed the task by setting up bodies charged with preventing river pollution and gave powers of control over the amount and nature of discharges from sewage works and elsewhere. During the period in which this statutory code for the safeguarding of our waters has been enacted, there has also been increasingly vigorous and successful reassertion of riparian owners' established common law right to enjoy unimpaired the flow and quality of the water passing their property.

The special responsibility of sewerage authorities

148. It is thus nowadays increasingly necessary, in the interests of public health and amenity backed by statutory and common law requirements, for sewerage authorities whose works discharge effluents into rivers to try, and to be helped, in all ways possible to ensure that those effluents contain nothing that might conceivably worsen the quality of the river water or the purity of any supplies taken for human consumption downstream. The means open to sewerage authorities for this purpose are of two main kinds: first, the provision and effective operation of treatment plant adequate as far as practicable to purify the sewage flows they receive; and secondly the exercise of such statutory powers as they possess to ensure that the sewage they do receive is as far as possible free from ingredients that would make ineffectual its treatment by known methods with the plant that is, or could reasonably be made, available. Sewerage authorities rightly place the main emphasis on the first means: they serve communities with continuously changing and usually growing needs, and have a duty to meet these needs as far as they can. This requires flexibility, resourcefulness, foresight and a willingness to experiment in sewage disposal practice; a large part of the success that sewerage authorities have achieved so far in dealing with their problems has been due to the possession and exercise of these qualities by their engineering and chemical staff, and to the pride which the authorities themselves, also, take in trying to serve and safeguard their own and neighbouring communities. Nevertheless it must be stated that the achievement of present standards of effluent quality has been largely due also to the fact that, until recently, the domestic sewages forming the bulk of the flows received at most sewage works have consisted almost entirely of matter that can be satisfactorily treated by settlement and biological oxidation, and can thus afford effective dilution for the more complex accompanying flows from trade premises.

The impact of synthetic detergents

149. The advent of synthetic detergents based on surface-active materials of the kind at present mostly used has altered this situation. Because of their widespread use, domestic sewage now contains complex compounds which are not completely destroyed during sewage and water treatment—compounds that give indications, some slight but some clearly positive, of the power to exercise adverse effects at successive stages throughout the progress of waste waters from domestic drains, through sewage works, down rivers, and (so far as a quarter of the population is concerned) through waterworks—whence there travels back to the domestic consumer, in the drinking water, a new added ingredient of no apparent benefit and of unknown long-term effect.

150. In other words domestic sewage is now for the first time taking on—albeit to a limited extent as yet—a characteristic (the presence in it of substances potentially harmful to, and not readily removed by, available methods of sewage treatment) formerly found only in trade effluents. As mentioned above, Parliament decided in 1937 that the mere potential possession of this attribute by trade effluents justified subjecting their discharge into public sewers, however desirable for other reasons, to a system of detailed regulation sometimes extending even to outright prohibition. These statutory provisions have played an essential part in protecting vital public services against danger to their operation. But they do not deal with any danger which might threaten from domestic sewage. In 1937 there was nothing to show that domestic sewage in general was one day to contain ingredients likely to give rise to difficulty of this kind. The fact that, in the growing use of household synthetic detergents of the present common type, such a difficulty, or the risk of it, is now seen to be arising is of importance in two ways. It indicates a narrowing of the never very wide margin of safety on which sewage works and waterworks have to operate. And it also shows up a gap in the statutory defences on which the community has hitherto relied to protect itself from its own wastes. This development should not be overrated: synthetic detergents cannot be said to be causing, or to be likely to cause, trouble of anything like the same order of severity as would arise if there were no control over the nature and volume of discharges to public sewers from trade premises. But it cannot be ignored.

151. Thus the growing use of synthetic detergents provides a peculiarly interesting example of the impact of the growth of scientific knowledge and invention upon our daily life. There have been discovered substances that, appropriately presented in a form suitable for household use, offer material advantage and desirable convenience. If the matter ended there, no problem would arise and the advent of these new aids to the performance of essential domestic tasks would be simply a matter for an exchange of congratulations between inventor, manufacturer, and housewife. Unfortunately the matter does not end with the purchase of the synthetic detergent product and the ultimate discharge of its residues to the household drain. Behind the advantages of its use there lie the difficulties, expense and risk to which its disposal after use may give rise. The advantages—enjoyed by the majority of the community in their capacity as individual consumers—are immediate and obvious, but they are advantages of, in the last analysis, convenience and not necessity. The difficulty, expense and risk are indirect, variable and imprecise; they may not always immediately affect more than a limited section of the population; but

they arise in public services vital to the health and welfare of the community as a whole. It is for consideration whether the community can really afford, consistently with its safety, to pay for the advantages in this way. Certainly, if there is any possibility that the advantages which the consumers want can be obtained at a smaller cost in terms of risk to the environmental services which protect them and their neighbours, it should be pursued as a matter of public importance.

The warning for the future

152. Fortunately the present situation is not one of great urgency. The various effects and risks we have described are not yet generally severe; in some areas, indeed, they are only slight, and may remain so; and their importance will vary considerably with different local circumstances. But their liability to occur is with us, and their seriousness when they do occur is likely to become more acute as our rivers continue to be used as receptacles for sewage effluent, and as sources of water supply, to an ever-increasing extent. It is true that, judging by the evidence we have obtained, there may not often be very much real difficulty so long as river flows keep up to their normal levels. But the safeguarding of rivers and of water supply must take into account extreme drought conditions, also. It is largely by reference to *minimum* flows that sewerage authorities, water undertakers and other who use rivers have to regulate their practice. If in one week a fishery is ruined, or water undertakers are unable to give their consumers a supply that is safe to drink, it will be little consolation that in the other 51 weeks of the year the river was clean. The evidence available needs therefore to be taken as a warning—against the risk to the environmental health services which seems inherent in the nature of the household synthetic detergents now commonly sold, and also against the possibility that other new domestic products having similar or even more serious effects might come into equally widespread use.

Possible remedial measures

153. From what we have said earlier it should be clear that there is little ground for confidence that the risks and difficulties discussed could be completely disposed of by a mere increase in expenditure on purification plant at sewage works and waterworks beyond what would otherwise be needed. Sewerage authorities and water undertakers are bound to meet new problems from time to time, and have a duty to take all possible steps to solve them, but some of the problems we have been discussing are of a kind that experience has shown they cannot be expected to solve unaided, though they must continue to do all they reasonably can.

154. It might be argued that the difficulty could be met if the discharge to a public sewer, by householders, of synthetic detergent residues of the kind intractable to sewage treatment, could be prohibited by local authorities under Section 27 of the Public Health Act (mentioned above) as being

> "matter likely to . . . affect prejudicially the treatment and disposal of its [the sewer's] contents"

wherever they were satisfied that serious difficulty in treatment and disposal would in fact arise. It is doubtful, however, whether discharges of synthetic detergents from individual households should properly be regarded as being covered by this provision. Besides, any system of restricting in this way what

is discharged to public sewers must inevitably be subject to wide variations in practice between one district and another. For discharges from trade premises, over which a large measure of control does already exist, the exercise of the control is indeed a matter of local discretion (subject in certain circumstances to appeal to the Minister); but that is because trade effluent problems are largely local in both their origins and their nature. The troubles that are or may be caused by synthetic detergents, however, are broadly similar in kind (if not in extent) wherever they occur, and they arise from the manufacture and sale of household products on a national basis. There is therefore much less reason for leaving to local discretion the determination of the extent to which they should be admitted to public sewers. Moreover a great deal of inconvenience would be caused to both users and manufacturers by the variations in practice which the existence of such discretion would inevitably entail.

155. In any case the enforcement of a prohibition at the point of discharge to the sewers would be impracticable and invidious. Sewerage authorities and synthetic detergent manufacturers alike are there to serve the public. The function of sewerage authorities is to take the drainage from houses in their district, not to decline to take it. The function of household synthetic detergents is to assist people in keeping their homes and possessions clean, not to get them into trouble with their local authority.

156. The fact that the advantages of household synthetic detergents are greatest in hard water areas might be thought to indicate that a remedy for the risk or difficulties to which they give rise could usefully be sought in some means whereby it became the universal practice, in all hard water areas, to soften the water before use. We do not believe, however, that this, even if thought practicable, could be achieved for many years, and it would certainly entail in total a very heavy cost. Moreover it would not necessarily reduce very substantially the demand for synthetic detergents; these products are nowadays used quite extensively even where the water supply is soft already. We have therefore not pursued this suggestion.

Conclusions and Recommendations

157. We have concluded that the key to the problems posed should be sought in an effort to find means whereby on the one hand consumers would be able to go on enjoying the many advantages which the use of household synthetic detergents can give, while on the other hand the surface-active ingredients of these products would be readily decomposed or otherwise removed at sewage works and so would cause little or no risk or nuisance to the public health services. The aim should also be to ensure that the continued use of synthetic detergents does not result in a greater increase in the phosphate content of rivers than experience shows to be prudent. This calls for continued and indeed extended research and experiment by sewerage authorities and by manufacturers of washing products.

158. Continued research and experiment by sewerage authorities may do much to help in clarifying the problem and pointing the way to a solution. But there can be no certainty that their efforts alone, even if accompanied by considerable expenditure on otherwise unwanted or premature changes and extensions to the design and operation of their works, will enable an effective and complete answer to be found so long as household synthetic detergents are based on the type of

alkylarylsulphonates used in this country during the last few years. The only practical way at present known, or likely ever to be available and acceptable in the foreseeable future, of adequately purifying the sewage of modern communities, is by biological oxidation. For biological oxidation to be successful in decomposing these particular alkylarylsulphonates at the rate and to the full extent necessary, filters and activated sludges at sewage works would have to develop bacterial flora capable of achieving this result during their primary task of decomposing the normal organic content of the sewage flow. The alkylarylsulphonates referred to, however, have been present in nearly all sewage for several years. During this time, at sewage works all over this country, many thousands of generations of sewage-decomposing bacteria have succeeded each other, without exhibiting at any works of which we have heard the property of readily and completely decomposing also these particular materials. It would therefore be optimistic to rely on flora more efficient in this respect developing naturally at sewage works in the future. It is conceivable that research might lead to the development of the desired flora by some deliberate means, and this possibility should be investigated if resources are available, but here again the prospects of success cannot be rated at a high level.

159. It is therefore essential that at the same time an urgent investigation should be made by manufacturers of washing products into the feasibility of replacing the present common types of household synthetic detergent by products of similar efficiency, but based on surface-active materials less resistant to known methods of sewage treatment than those at present used. As explained earlier in this report, there is already one particular surface-active material—a secondary alkyl sulphate—which has been shown to be readily destroyed during the biological oxidation of sewage. This particular material, like the primary alkyl sulphate also used in certain products, has not so far proved suitable for the formulation of efficient all-purpose household washing powders. But we do not know whether, to be suitable in this respect, a surface-active agent *must* also be resistant to biological oxidation. Recent investigations both in this country* and in the United States† have suggested that the extent or rate of oxidisability of anionic surface-active materials by bacterial action may depend not so much on the chemical type to which they belong (alkylarylsulphonate, secondary alkyl sulphate, etc.) as on their particular molecular structure. It may well be, therefore, that research can show means whereby whatever type of surface-active material is selected for its suitability in household washing products it can, by appropriate adjustments in the manufacturing processes from which it is derived or evolved, be produced in a form rendering it readily destructible in sewage treatment and therefore capable of doing little or no harm. At all events we have no reason at present to believe that the production of an efficient household detergent based on a surface-active material that can be readily oxidised at sewage works is impossible.

160. Any adjustment in manufacturing processes so as to achieve this object might well involve greater cost—at least initially. A similar difficulty will arise if, in the interests of river and waterworks purification, and in the absence of any success in obviating the problem by other means, changes prove necessary in synthetic detergent manufacture so as to reduce their content of certain

* J. Appl. Chem., 1955, 5, 517–524 (C. Hammerton).

† Sewage and Industrial Wastes, 1955, 27, 917–928 (R. H. Bogan and Clair N. Sawyer).

phosphates. But the implications now being revealed of the growing use of products of the kind we bave been referring to are such that the whole question of the selection of materials for household synthetic detergents clearly needs a fresh review, in which the interests of the public as consumers must be balanced against their public health interest as a community. Responsible manufacturers of washing products have already taken, and continue to take, great care in ensuring that their products are reasonably harmless in those directions where from long experience in the past they might bave expected any fears of harm to arise—for example, as regards effects on the skin or on the articles washed. Tbeir attention has now been drawn to what, for washing products, is a relatively new field of concern. We have uo doubt that they will wish to exercise the same degree of care in this field also, even tbough the effects of a lack of it may not be so directly apparent to the consumer.

161. In their efforts to achieve tbe position in which the surface-active ingredients of synthetic detergents are destroyed at sewage works, and the phosphate content of effluents is kept within prudent limits, sewerage authorities and synthetic detergent manufacturers will clearly nced to co-operate closely. For this purpose we feel that it will be necessary to set up some central co-ordinating body for the pooling of advice and the interchange of facilities, and the securing of any practicable improvcmcnt in the methods available for determining concentrations of surface-active material. Research by manufacturers on new ingredients, investigation by or on bebalf of sewerage authorities of methods of dealing with those and the present materials as well, and the testing of the results, will all need to be closely integrated if time and effort are not to be wasted. Tbere should, we fccl, be participation by such government departments and agencies as are most closely informed and concerned in the matters under investigation. It would be for this central co-ordinating body to keep the progress of tbe research under regular review, to watch for any signs of increasing difficulties or risks, and to assist sewerage authorities with advice on the various possible ways of meeting or palliating them.

162. It also seems highly desirable that regular dcterminations, by the most reliable available method, bc made of the concentrations of surface-active materials and phosphates present in all sewage effluents discharged in sizeable quantities into rivers or estuaries, and that watcr undertakers drawing supplies from such rivers should keep a similar check both on the raw water at their intakes and on the treated water they supply for public consumptiou. Tbe water undertakcrs' records of this information should be made available to the Health Departments, and the possibility of long-term ill-effects being caused to health by thc presence of surface-active materials in drinking water at the concentrations recorded should be kept under regular review.

163. The possibility must be faccd that the various kinds of research we have recommended may not yield fruitful results, in terms of disposing of the bulk of the problems we have discussed, for some considerable timc. The question arises whether thc public interest is sufficiently safeguarded meanwhile. Some might take the view that the widespread sale of any domestic product apparently liable to reduce the margin of safety of tbe public health services sbould not be allowed unless a competent authority has first been satisfied that no such undesirable consequence of its use can in fact arise. This is perhaps an extreme view. Certainly in the case of tbe products we bave been discussing we do not

think that the situation today is so serious, or is so clearly going to become more serious in the near future, as to justify our recommending the bringing of any such system of control into operation at this stage.

164. Indeed four of our number go further. They consider that it would be both unrealistic and undesirable to assume on present information that any real risk of a serious situation arising in the future, involving a need for control, exists at all. Their view is that whatever problem there is at present is unlikely to be materially increased by reason of further development of the household synthetic detergent market, since they expect the rate of growth in consumption to slow down considerably and they do not believe that manufacturers, having had the question of possible difficulties in disposal drawn to their attention, would introduce any new ingredient that could create or add to the difficulties feared. They are not satisfied that the present evidence about the effects of synthetic detergents is sufficiently reliable or conclusive to justify more than continued care and research. They believe that such research (particularly in the development and use of improved methods for determining concentrations of surface-active material in sewage, effluents and river water) may well show the problem to be significantly smaller than might, on the face of the present evidence, appear. They feel that in any case there is every hope that practicable remedies can be found (whether on lines already explored or as a result of a more radical approach) for such difficulties as are confirmed, after further investigation, to exist. They regard as especially significant in this connection the indications, in the evidence already obtained, that a number of sewage works and waterworks appear to have found means of limiting synthetic detergent residues, and their apparent effects, to a greater extent than at works elsewhere. They also attach great importance to the fact that the public health services have not generally failed in the past to extend their scope and adapt their practice in pace with the increasingly complex material progress of the community, and should not be assumed likely to fail in this task in the future—whether their problems arise from the advent of synthetic detergents or from more extensive developments of other kinds. These members therefore consider that any thinking, at this stage, in terms of control, even as a last resort, would unnecessarily divert attention from the real need confronting public authorities and manufacturers of synthetic detergents alike—which is to extend the investigations already begun, and to seek whatever means may be needed whereby the public can continue to have its chosen washing products while still enjoying the protection of efficient and safe public health services.

165. The majority of us, including the Chairman, are sufficiently impressed by the evidence already available to feel that the possibility (we put it no higher) of a serious situation arising before research has shown a practicable remedy, or even of the effects at present noted being found more serious than they are now rated, cannot in prudence be ignored. This majority opinion is that in either such eventuality the exercise of control over the composition of household synthetic detergents—presumably on the advice of some such body as is referred to in para. 161—would be necessary in the public interest—and might conceivably be needed at fairly short notice. Statutory powers for a control of this kind are not at present available. This majority of us therefore recommend that the Government should consider very carefully whether to seek these powers now, for holding in readiness as a safeguard for the public, or to defer obtaining them until a clear need for their exercise has arisen.

VIII. SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

Summary of Conclusions

166. Synthetic detergents are now in extensive use for a wide range of purposes, particularly as domestic washing products. They have considerable advantages, both industrially and in the home, one important advantage being that they are equally efficient in hard or soft water. Their use is still growing, though the rate of growth in the future may not be nearly so rapid as during the last few years.

167. Their composition varies according to the purpose for which they are required. By far the bulk of the tonnage sold nowadays, however, is made up of household washing powders that foam in water; they consist of anionic surface-active agents accompanied by a number of other ingredients including phosphates. It is these household products, rather than the various kinds of synthetic detergents used industrially, that give rise to any general problem.

168. When regularly used in contact with the skin, synthetic detergents can, like other washing products, cause dermatitis, particularly among those pre-disposed to this ailment, but their widespread use has not in practice led to any significant growth in the incidence of dermatitis and is not likely to do so if they are used in a sensible way.

169. If crockery, etc., is washed with synthetic detergents and drained dry without rinsing, some traces of synthetic detergent ingredients may remain on the surface and be ingested during subsequent use. But the amounts thus ingested must be minute, and there has been no evidence so far of any ill-effects, though the question of ingestion over a lengthy period needs long-term study.

170. The pronounced cleansing and foaming properties of most household synthetic detergents can cause certain troubles in some plumbing systems and household appliances, but such troubles do not appear to be serious, irremediable, or widespread.

171. The residues of nearly all synthetic detergents pass, after use, into sewers, most of which lead to sewage treatment works. Household synthetic detergents, which in practice contribute most of the residues thus arriving at sewage works, are mostly based nowadays on a particular type of anionic surface-active agent which does not appear to be readily or completely destroyed or otherwise eliminated during existing processes of sewage treatment. This appears to apply also to some of their accompanying phosphates.

172. In sewage treatment this has the following effects—most of which, however, vary widely in their incidence and degree from one area to another:—

(*a*) At most works using the activated sludge process, and at some works using percolating filters, foam occurs, or is liable to occur, to an extent that causes nuisance, and could in some cases endanger public health.

(*b*) At many works using either method of treatment the purification processes seem, on balance, liable to be retarded, and the general quality of the effluent therefore worsened; the provision of extra treatment plant to offset this effect could be costly.

(*c*) At virtually all works the effluent discharged contains some residual surface-active material and is likely also to have a higher phosphate content than formerly.

173. From most sewage treatment works the effluent is discharged to a river. The amenities of such a river (including its freedom from foam), its ability to support a healthy fish and plant life, and it preservation from offensive or toxic conditions, are in varying degrees liable to be adversely affected by the presence of synthetic detergent residues in the effluents thus discharged to it, as well as by any worsening in the general quality of those effluents brought about by the presence of synthetic detergent residues in the sewage works.

174. Rivers below sewage works outlets are used as sources of water supply for about a quarter of the population. To an important though widely varying extent the means of the water undertakers concerned to ensure the continued provision to their consumers of an adequate, pure and wholesome supply are liable to be strained:—

(a) by any worsening, of the kind mentioned, in the efficiency of sewage treatment upstream and thus in the general quality of the river water; and

(b) by the presence, in the river water abstracted, of residual ingredients of synthetic detergents which might in certain circumstances add to the difficulties of water purification.

Also, the surface-active material getting into river water from sewage works is apparently not being completely removed from the water by the purification processes at present available at the waterworks concerned, and traces of it must therefore be present in all the drinking water supplied from such waterworks to the public. No evidence that this could cause ill-effects is known, but the possibility of long-term effects needs to be kept under review.

175. Except as regards foam production at some sewage works, the risks and difficulties to which the use of synthetic detergents appear to be giving rise at sewage works, in rivers, and at certain waterworks, are limited and marginal, rather than widespread and acute. But in this age of increasingly complex social and industrial development our environmental health services are functioning without any large margin of safety, and can be kept safe only by continuous action to ensure that even slight possibilities of danger are minimised, if not avoided, wherever practicable. This is in large part the responsibility of the sewerage and water supply authorities, but one essential factor also is the maximum degree of exclusion from public sewers of materials intractable to sewage treatment. This is already secured, as regards trade discharges, by the operation of specific statutory restrictions. As regards domestic discharges, which form the bulk of most sewage flows, it has hitherto resulted only from the fact that until recent years there was no widespread use domestically of products which could cause sewerage authorities any special trouble. With the advent of household synthetic detergents of the present relatively stable type it seems that the situation is being altered for the worse. There is no cause at present for alarm, but there is need for concerted effort to safeguard the position as soon as possible.

Summary of recommendations

176. We recommend that:—

(a) Further improvement should be sought in the methods available for determining small concentrations of surface-active material in sewage, sewage effluents, and water.

(*b*) Regular determinations should be made of the concentrations of surface-active materials and phosphates present in all sewage effluents discharged in sizeable quantities into rivers.

(*c*) Water undertakers drawing supplies from such rivers should make regular determinations of the concentrations of surface-active materials (and, where appropriate, of phosphates) present both in the raw water at their intakes and in the treated water they supply for public consumption.

(*d*) The information thus obtained about the concentrations of surface-active materials in public water supplies should be made available to the Health Departments.

(*e*) The possibility of long-term effects on health being caused by the drinking of water containing such concentrations, or by the use of crockery, etc., washed with synthetic detergents and not rinsed, should be kept under permanent medical review.

(*f*) Investigations should be further pursued at selected sewage works into the possibility, with existing or new methods of treatment, of effecting more rapid and complete destruction or elimination of the main ingredients of the present common types of household synthetic detergents, and the suppression of any foam nuisance to which their presence during purification gives rise.

(*g*) At the same time, manufacturers of household synthetic detergents should investigate the feasibility of producing efficient washing products based on materials which can be readily oxidised or eliminated, and will not cause persistent foaming, during sewage treatment by present available methods.

(*h*) An advisory body including representatives of the sewerage authorities and manufacturers concerned, and of appropriate government departments, should be set up to give counsel and facilitate research on all these matters; to keep the progress of the research under review; and meanwhile to watch the position at sewage works, on rivers, and in the waterworks concerned, in relation to the continued use of synthetic detergents of the present common type.

177. The question arises whether the public interest is sufficiently safeguarded while the recommended research is being carried out. Four of our number do not consider the present evidence of difficulty or risk to be so reliable or conclusive as to suggest that any need for special safeguards could arise. The majority of the Committee believe that a worsening in the situation, justifying control of the composition of synthetic detergents, is not inconceivable; they draw attention to the lack of any powers for the exercise of such a control, should it prove necessary, and to the question whether such powers should be obtained now and held in readiness, or not until a clear need for their exercise arises.

178. Throughout our deliberations as a Committee, we have been greatly aided by the Technical Officers appointed to work with us—Dr. E. A. B. Birse, Lieut.-Col. F. G. Hill and Dr. A. Key. Their guidance in the collation and interpretation of the extensive and varied evidence we have had to deal with has been most valuable, and we are very grateful for their unfailing helpfulness—as also for the special additional assistance we received from two officers of your Department, Mr. R. A. Elliott and Mr. A. W. Kenny.

179. But particularly do we wish to record our indebtedness to our Secretary, Mr. A. R. Isserlis. He has dealt most efficiently with the very large number of documents that we have had to study, and his appreciation of the problems with which we have been faced has enabled him to render outstanding service during the drafting of this report. By his skill and tact many difficulties have been resolved.

We have the honour to be, Sir,
Your obedient Servants,

(Signed) H. JEPHCOTT (*Chairman*)

N. R. BEATTIE	J. R. NICHOLLS
C. E. BOAST	F. T. K. PENTELOW
J. C. CRUICKSHANK	B. A. SOUTHGATE
G. H. W. CULLINAN	J. H. STREET
R. H. GREENLY	W. L. THOMAS
G. MACROBBIE	C. B. TOWNEND
F. D. MORRELL	E. WINDLE TAYLOR

A. R. ISSERLIS,
Secretary

30th December, 1955

APPENDIX A

Determination of Anionic Surface-Active Materials in Sewage, Sewage Effluents, and River Waters

The revised method of determination referred to in paragraph 6 of the Report was described in a paper entitled "Determination of Anionic Detergents in Sewage, Sewage Effluents and River Waters", by J. Longwell and W. D. Maniece, which at the Committee's request and with the permission of the Government Chemist was published in "The Analyst", 1955, 80, 167. Following is an extract from that paper.

Method

Reagents

Alkaline phosphate solution—Dissolve 10 g of analytical-reagent grade disodium hydrogen phosphate (anhydrous) in distilled water. Adjust the pH to 10 by addition of sodium hydroxide and make up to 1 litre with distilled water.

Neutral methylene blue solution—Dissolve 0·35 g of B.P. methylene blue in distilled water and make up to 1 litre.

Acid methylene blue solution—Dissolve 0·35 g of B.P. methylene blue in about 500 ml of distilled water, add 6·5 ml of analytical-reagent grade sulphuric acid and make up to 1 litre with distilled water.

Chloroform—Analytical-reagent grade (it may be recovered after use by distillation over burnt lime.)

Manoxol O.T. solution—Dissolve 0·100 g of Manoxol O.T. (sodium dioctylsulphosuccinate) in distilled water and make up to 1 litre. Dilute 10 ml to 100 ml with distilled water to give a standard solution of 10 p.p.m.

Procedure

(i) The volume of sample taken should be chosen when possible to contain 20 to 150 μg of anion-active material. It is generally impracticable to take more than 10 ml of raw or settled sewage, owing to the degree of emulsion formation on shaking with chloroform, but it is possible to take up to 100 ml of good quality effluent, river and drinking water when the detergent content is very low.

(ii) Place the sample in a separating funnel and make up to 100 ml with distilled water. Add 10 ml of alkaline phosphate solution, 5 ml of neutral methylene blue solution and 15 ml of chloroform.

(iii) Shake gently and evenly twice a second for 1 minute. Allow to separate, breaking up any emulsion formed in the separator by gentle agitation with the flattened end of a glass rod. Run the clear chloroform layer into a second separating funnel containing 110 ml of distilled water and 5 ml of acid methylene blue solution. Rinse the first separating funnel with 2 ml of chloroform added from a burette and run this into the second separating funnel.

(iv) Shake the second separating funnel as in (iii) and allow the layers to separate. Run the chloroform layer through a small funnel plugged with cotton wool moistened with chloroform into a 50-ml calibrated flask, rinsing with a further 2 ml of chloroform.

(v) Repeat from (iii) with two further 10-ml portions of chloroform and make up the combined extracts in the flask to the mark with chloroform.

(vi) Before carrying out a further determination, the separating funnels should be rinsed with dilute nitric acid to remove adsorbed methylene blue.

Sulphide interference—Sulphide, if present, should be oxidised before extraction. Place the required volume of sample in the first separating funnel, add 10 ml of alkaline phosphate solution and 2 ml of 20-volume hydrogen peroxide. Stand for 5 minutes and bulk to 110 ml with distilled water. Add 5 ml of neutral methylene blue solution, 15 ml of chloroform and proceed as in (iii) above.

Measurement—The optical density of the chloroform extract is measured in a suitable photo-electric absorptiometer either at 650 mμ or with an Ilford No. 607 orange filter.

Calibration—Suitable volumes (5, 10, 15 and 20 ml) of the dilute Manoxol O.T. solution are treated as above and the optical densities of the extracts determined. The optical density of a reagent-blank extract is also measured. This is constant for a given batch of reagents. In this sense, distilled water is a reagent and the same water and other reagents should, therefore, be used throughout one day, during which the reagent blank is determined.

The differences between the optical densities of the standards and the reagent blank are plotted against concentrations to give a calibration curve. The detergent concentration of a sample can then be determined from this curve. In practice, the calibration curve is a straight line and optical density can be converted to concentration by use of a factor based on the slope of the line.

APPENDIX B

Surface-Active Materials used in Synthetic Detergents

The three main classes of surface-active agents used in synthetic detergents (referred to in paragraph 11 of the Report) are:—

(*a*) *Anionic agents* which ionise or dissociate in solution to give an amphipathic (i.e. having a dual sympathy for oil and for water) anion and a small, usually metallic, cation, the anion being the active part of the molecule. These agents are generally salts of the alkali metals with strong organic acids, the two sub-classes most commonly in use being:—

(i) *alkyl sulphates* produced by sulphating either primary fatty alcohols (typical formula $R{-}OSO_3Na$, where R = higher alkyl radicle) or secondary alcohols (typical formula

$$\begin{matrix} R_1 \\ R_2 \end{matrix}\!> CH.OSO_3Na$$

where R_1 = higher alkyl radicle and R_2 = higher or lower alkyl radicle) and

(ii) *alkylarylsulphonates* produced by sulphonation of an aromatic hydrocarbon (usually benzene) alkylated with a special petroleum fraction or similar synthetic hydrocarbon (typical formula $R.C_6H_4.SO_3Na$ where R = alkyl radicle containing 9 to 15 carbon atoms).

(*b*) *Cationic agents* which ionise in solution to give an amphipathic cation and a small anion (usually a halide), the cation being the active part of the molecule. Typical of this class are the quaternary ammonium salts (general formula

$$\begin{matrix} R_1 \searrow \\ R_2 \\ R_3 \\ R_4 \nearrow \end{matrix}\!> N.X.$$

where R_1, R_2, R_3 and R_4 = alkyl groups of which one is of higher molecular weight and X = halide). Generally speaking these agents are ineffective in alkaline solution and are not used in domestic detergents.

(*c*) *Non-ionic agents* which do not ionise in solution. These include the ethylene oxide addition compounds (typical formula $R{-}(OCH_2.CH_2)_n{-}OH$, where R = an alkyl or an aryl radicle), monoesters of hydroxy compounds and various amides and sulphonamides.

APPENDIX C

Guide to Literature

Some papers reviewing current literature on synthetic detergents

The effects of synthetic detergents on sewage purification: a summary of current knowledge. Lumb, C. *Wat. Sanit. Engr.* 1952, 3, 7–11, 25, and 53–57.

American Chemical Society's Symposium "Effect of detergents on sewage and water treatment". *Chem. Engng News*, 1953, **31**, 1072–1079.

Synthetic detergents: their effects on sewage treatment and water supply. Isaacs, P. C. G. *Wat. Sanit. Engr.* 1953, 3, 413–420 and 453–457. (Reflects British and European experience.)

Chemical structure and action of synthetic detergents. Gowdy, W. R. *Sewage Industr. Wastes*, 1953, **25**, 15–19.

Action of detergents in sewage treatment—a study by industry. Gowdy, W. R. *Sewage Industr. Wastes*, 1953, **25**, 255–261.

Characteristics and effects of synthetic detergents. American Water Works Association Task Group E5–15. *J. Amer. Wat. Wks Ass.*, 1954, **46**, 751–775 (includes references to reports on skin and oral toxicity).

Reports on the progress of applied chemistry. *Society of Chemical Industry*, 1954, Vol. 39, 404–411, 1953, Vol. 38, 365–374, and 1952, Vol. 37, 596–600 (Section on detergents).

Synthetic detergents and their effects on sewage treatment and water pollution. A review of literature. Smith, R. S., Walton, G., and Cohen, J. M. U.S. Dept. Hlth, Educ. and Welfare, 1954, June.

The public health significance of synthetic detergents—Bulletin No. 2 (Feb. 1955) of the Department of Civil Engineering, King's College, University of Durham.

The use of household detergents and their dangers. Hodgson, G. *The Practitioner*, 1953, **170**, 166 (a discussion of possible effects on the skin).

Some publications in which papers on the effects and nature of synthetic detergents appear from time to time

Sewage and Industrial Wastes—Annually (May–June) the previous year's literature is reviewed.

Water and Water Engineering.

Journal of the Institution of Sanitary Engineers.

Journal and Proceedings of the Institute of Sewage Purification.

Journal of the American Water Works Association.

Journal of the American Pharmaceutical Association.

Water and Sewage Works.

Bulletin du Centre Belge d'Etude et de Documentation des Eaux.

Le Technique Sanitaire et Municipal.

Journal of Applied Chemistry.

The Analyst.

Water Pollution Research (the annual report of the Water Pollution Research Board and of the Director of Water Pollution Research).

Water Pollution Abstracts.

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Staffordshire Sentinel photograph

Foam at Stoke-on-Trent, January 1953

Foam at Motherwell, May 1954